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PRESENT STATUS OF FLNR (JINR) ECR ION SOURCES

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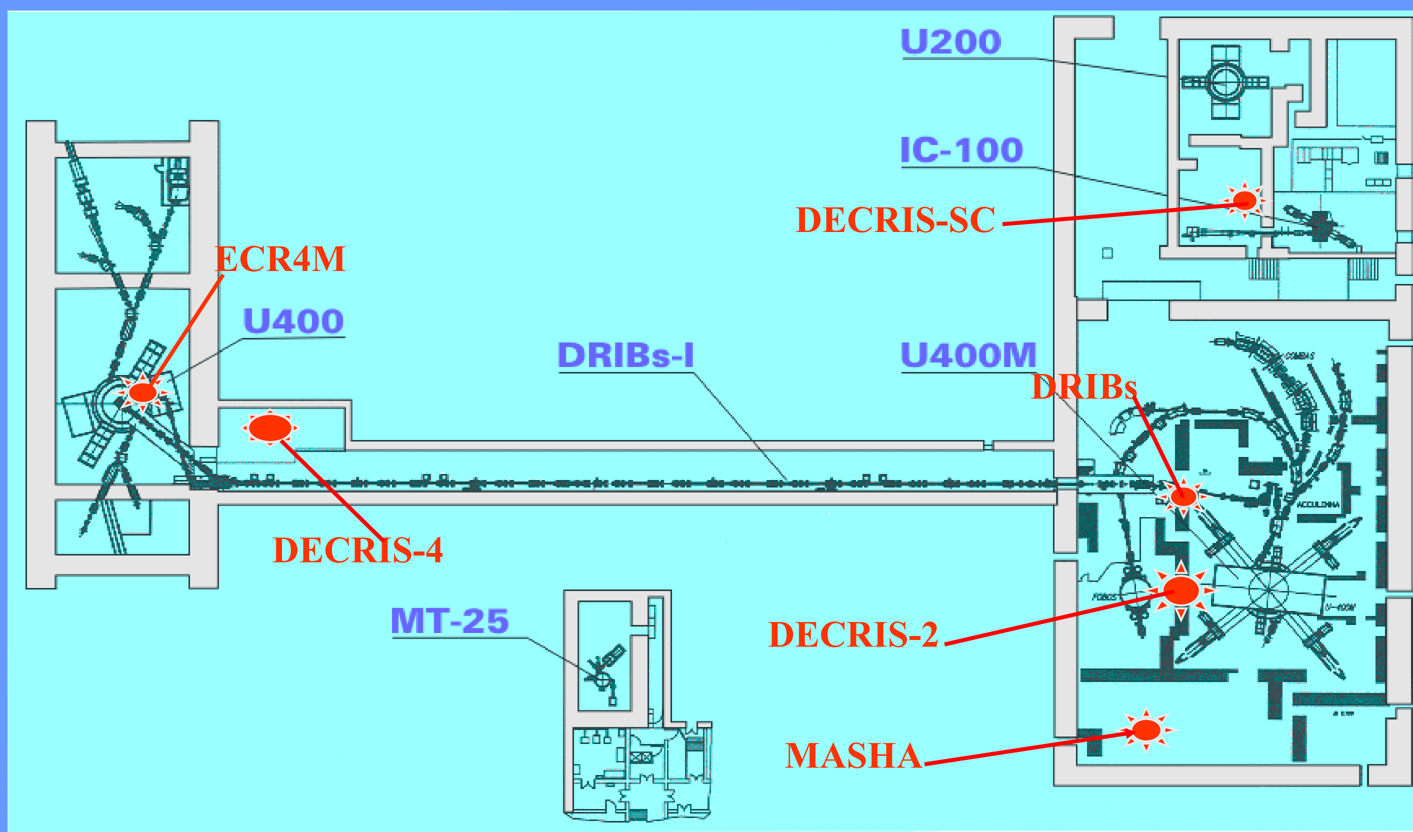
FLNR (JINR) CYCLOTRONS WITH ECR ION SOURCES

U400 + ECR4M

U400M + DECRIS-2

CI-100 + DECRIS-SC



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DECRIS - Dubna ECR Ion Sources

DECRIS-2, DECRIS-2m, DECRIS-3, DECRIS-4 are "room temperature" ECR ion sources. The axial magnetic field is created by the coils with independent power supplies. The radial magnetic field is created by permanent magnet hexapole, made from NdFeB.

DECRIS-SC – axial magnetic field is created by superconducting solenoids

DECRIS-2 – U-400M cyclotron – 1995

ECR-4M – U-400 cyclotron – 1996 (collaboration FLNR – GANIL (France))

DECRIS-3 – TESLA Accelerator Installation (Belgrade) -1997

DECRIS-2m – BIONT Inc. (Bratislava) – 2003

DECRIS-SC – CI-100 cyclotron - 2004

DECRIS-3 - DC-60 accelerator complex (Astana, Kazakhstan) – 2006

DECRIS-4 – in operation at the test bench - 2005

DECRIS-2m – tested → DC-72 cyclotron (Bratislava)

DECRIS-SC2 – new ion source for U-400M – under commissioning

DECRIS-5 – for DC-110 cyclotron – project/production

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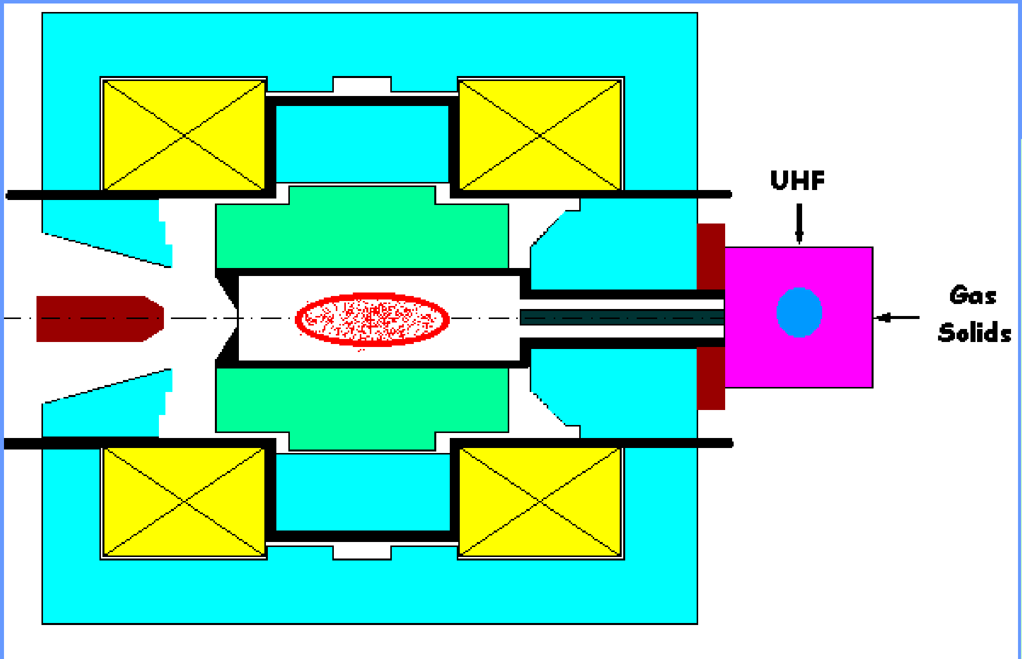

DECRIS-2

AXIAL MAGNETIC FIELD	
Peak on axis, injection side	1.2 T
Peak on axis, extraction side	0.85 T
Length of the main stage mirror	19 cm
HEXAPOLE	
External diameter, central part	19 cm
External diameter, end part	16 cm
Internal diameter	7 cm
Hexapole length	20 cm
Hexapole field on the chamber wall	1.1 T
PLASMA CHAMBER	
Internal diameter for the main stage	6.4 cm
Internal diameter for the injection part	2.9 cm
Length for the main stage	22 cm
SOLENOID	
Solenoid number	2
Internal diameter	18 cm
External diameter	34 cm
Typical coil current	950 A
Maximal coil current	1300 A
Typical power consumption	< 60 kW
Cooling water pressure	5 Bars

The source is in regular operation at the U400M since 1995

Since 2008 the cyclotron operates in two modes:

high-energy ion beams (A/Z = 3 – 5)

Li, B, C, N, O, Ne, S ions with energies of 35 -55 MeV/n for generation secondary beams of ^{6}He, ^{15}B, ^{9}Li, ^{11}Li, ^{12}Be, ^{14}Be, ^{8}He.

low-energy ion beams (A/Z = 8 – 10)

Ne, Fe, Kr, Xe, Bi ions with the energies of 5 – 9 Mev/n for experiments in nuclear physics (SHE) and material physics

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DECRIS-2 at the test bench

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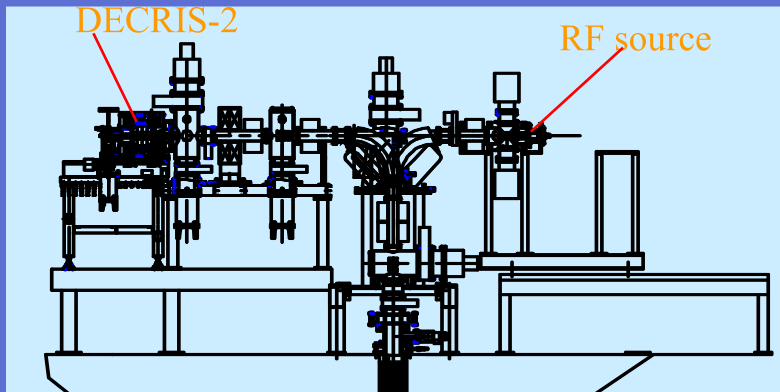
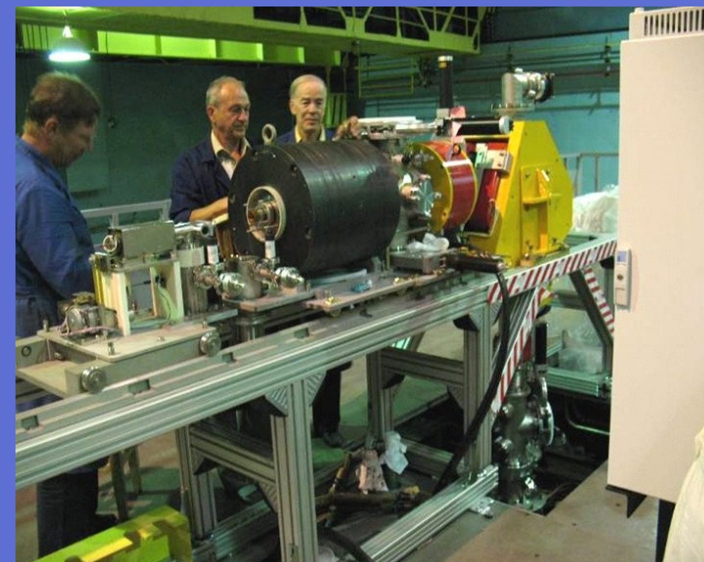
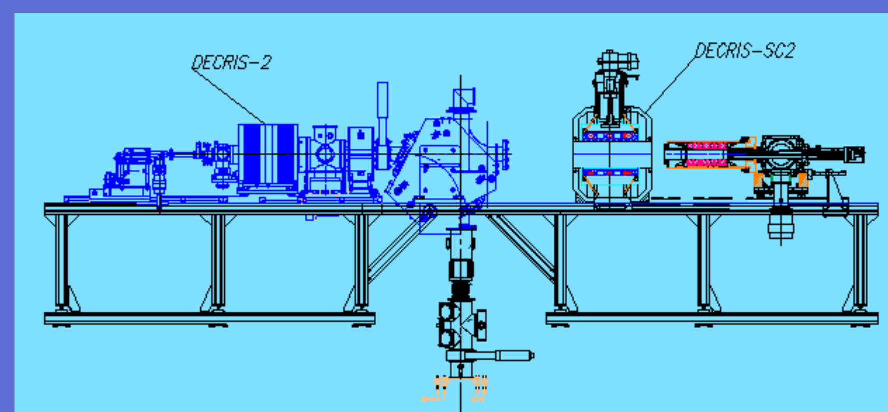
Modernization of the U-400M axial injection system, 2007







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TYPICAL ION CURENTS (eμA)

Ion	Li	B	O	Ar	Kr	Xe
2+	300					
3+	70	200				
4+		80				
5+			660			
6+			450			
7+			40			
8+				600		
9+				340	100	
18+						45
20+						40

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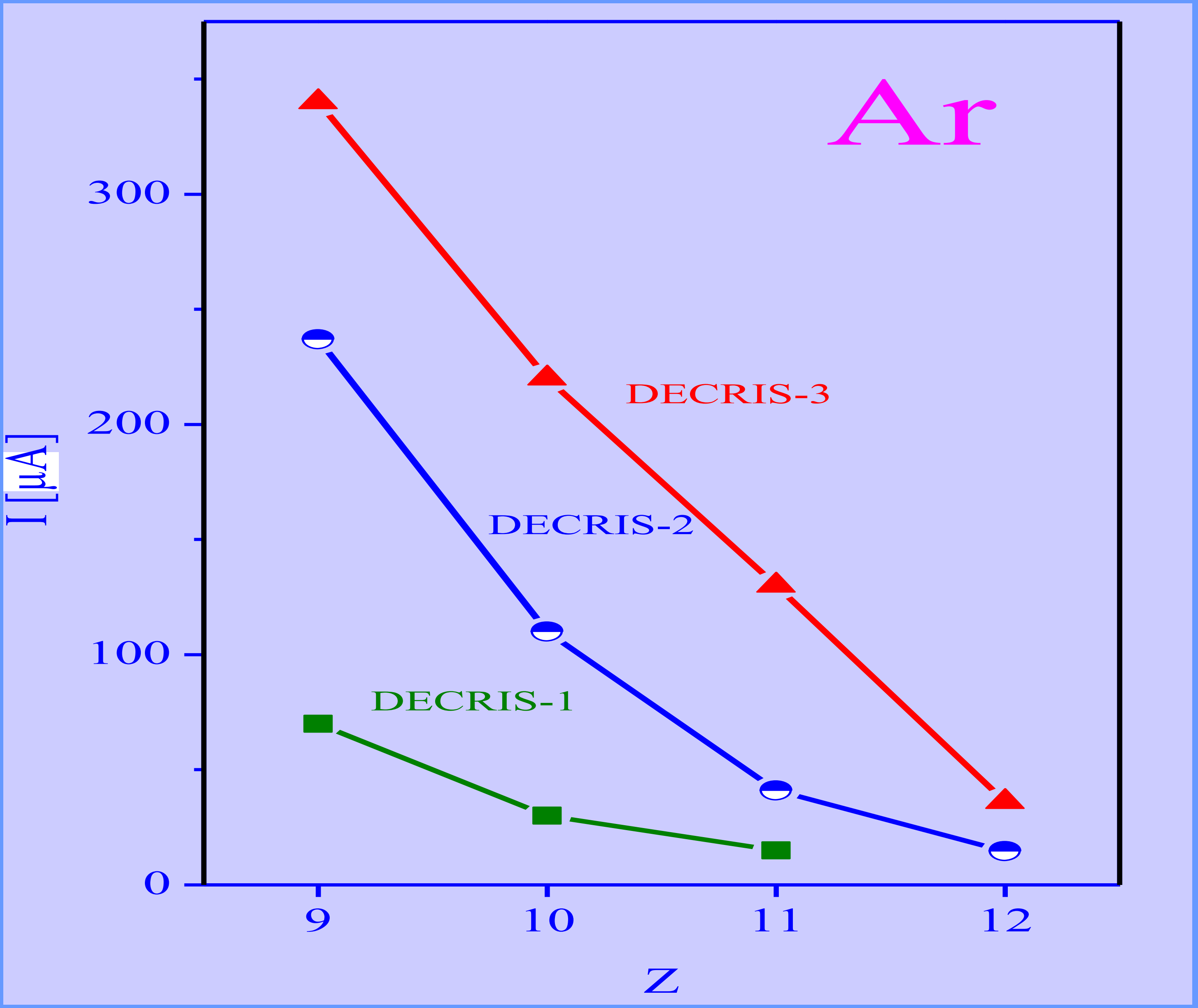
Development of DECRIS



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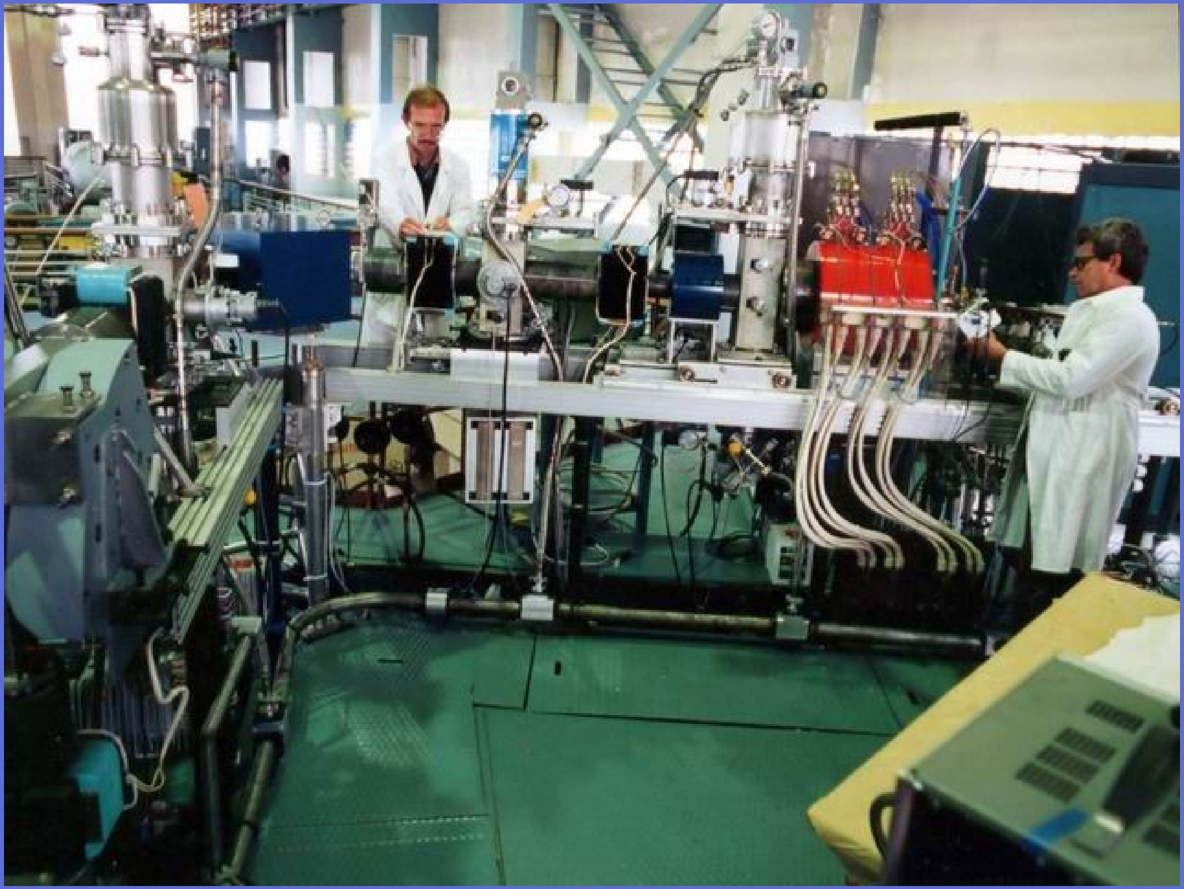
The ECR4M source and the axial injection system were assembled and commissioned in 1996.

First accelerated Ar beam – November 1996. First accelerated ^{48}Ca beam – November 1997.



About 66% of the total time since 1997 were used for acceleration $^{48}Ca^{5+}$ ions for synthesis of new superheavy elements. Within the mentioned period elements with Z = 113, 114, 115, 116, 117, 118 were synthesized. Chemical properties of Z = 112 were studied. The ^{48}Ca beam intensity on the target is 8 10^{12} pps (1.2pμA)

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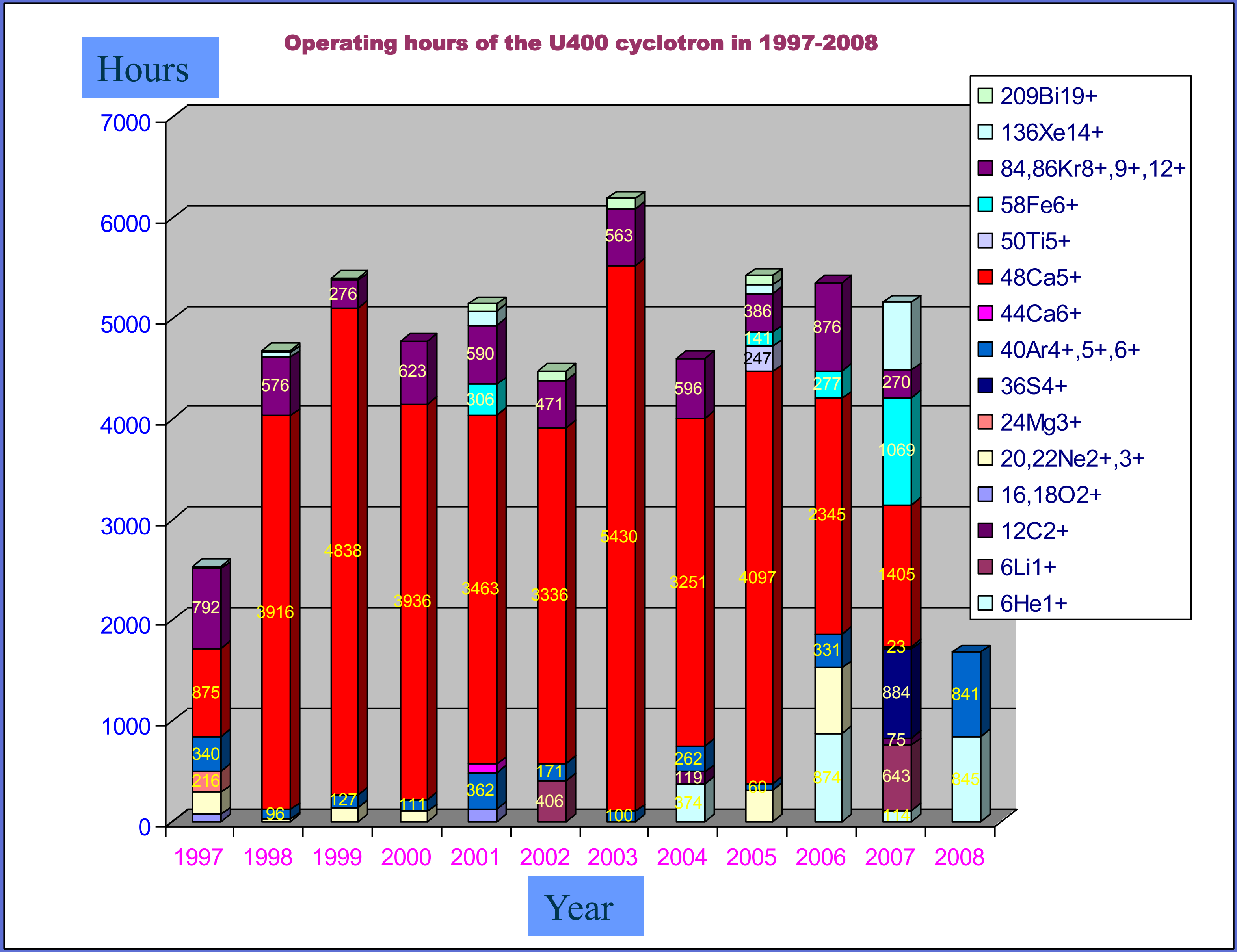
Operating hours of the U400 cyclotron in 1997-2008
Hours
7000
6000
5000
4000
3000
2000
1000
0
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
Year
209Bi19+
136Xe14+
84,86Kr8+,9+,12+
58Fe6+
50Ti5+
48Ca5+
44Ca6+
40Ar4+,5+,6+
36S4+
24Mg3+
20,22Ne2+,3+
16,18O2+
12C2+
6Li1+
6He1+
792
875
340
216
576
3916
96
276
4838
127
623
3936
111
590
306
3463
362
471
3336
171
406
563
5430
100
596
3251
262
119
374
386
141
247
4097
60
876
277
2345
331
874
270
1069
1405
23
884
75
643
114
841
845

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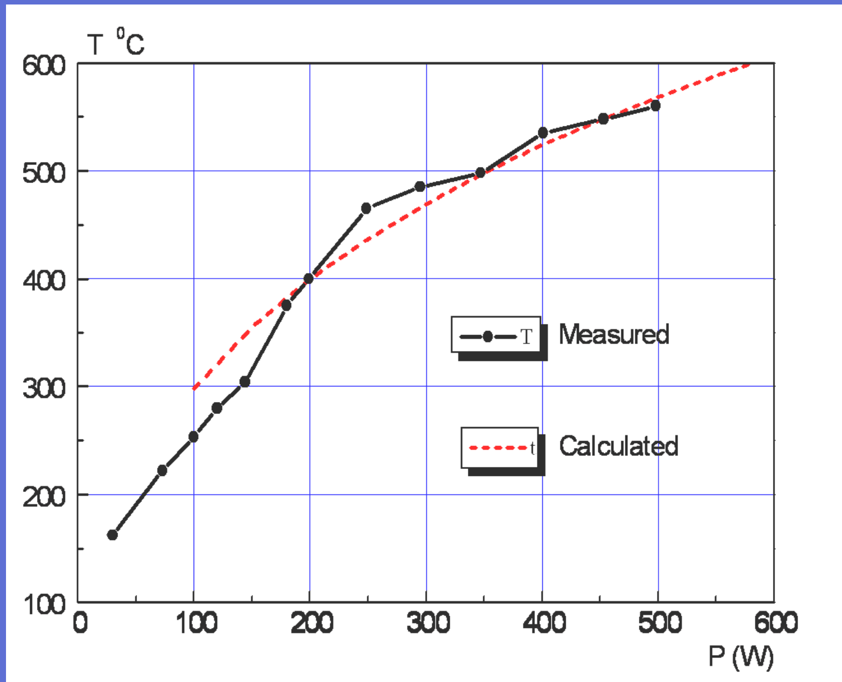
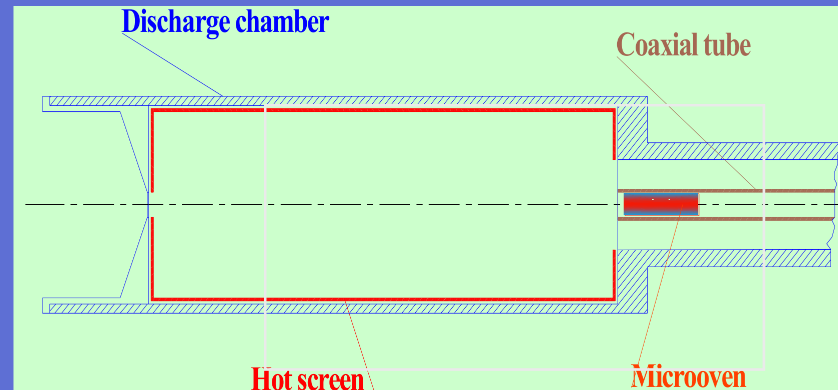
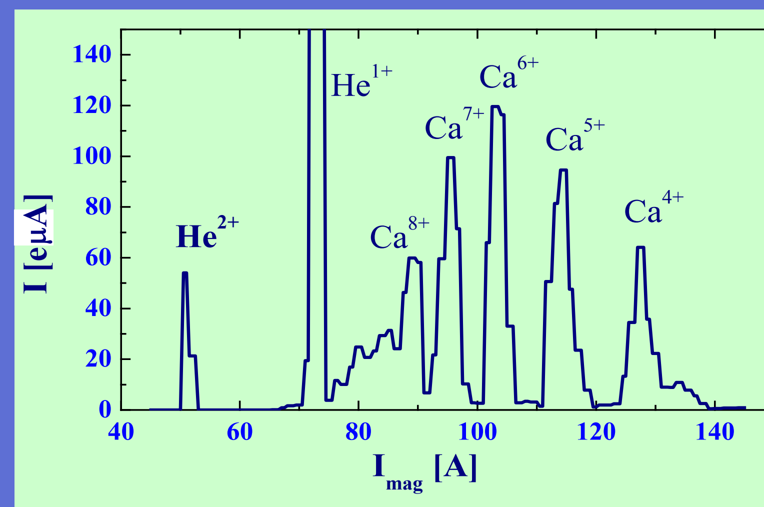
Production of the ^{48}Ca ion beam

581 samples of metallic ^{48}Ca were used since November 1997 till July 2010



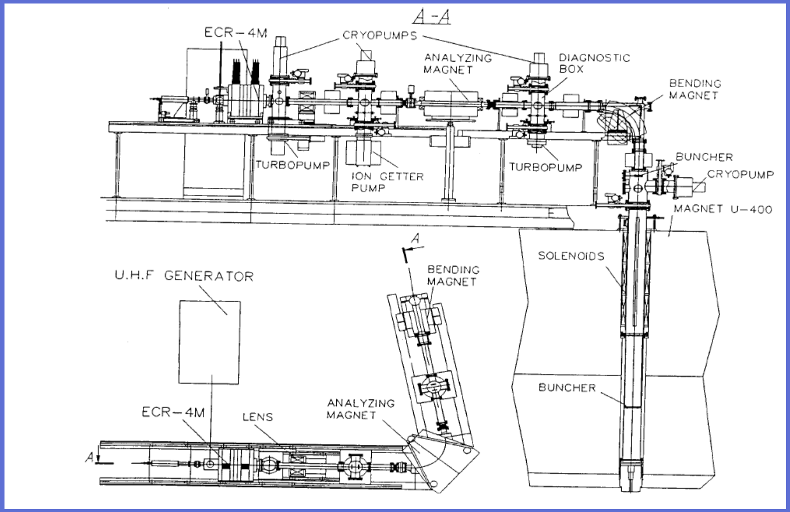
The screen is heated by microwaves and plasma electrons.

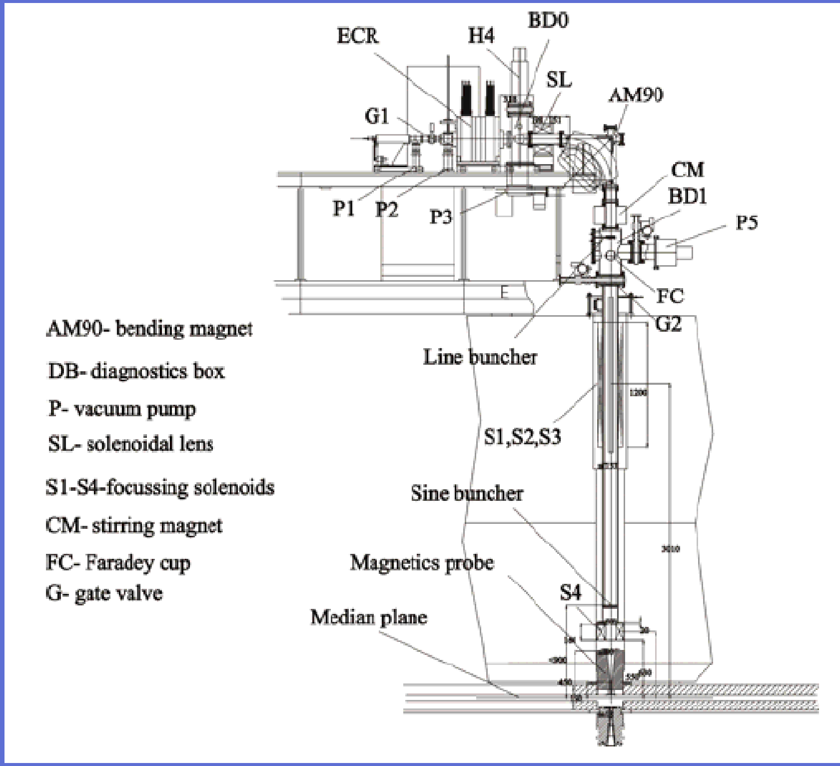




Ca spectrum with hot screen

2002: modernization of the U400 axial injection included sharp shortening the injection channel horizontal part. As the result, the distance from the electron cyclotron resonance ion source to the vertical analyzing magnet became equal to 730 mm. These changes allow us to increase the $^{48}Ca^{18+}$ ion intensity at the U400 output from 0.9 to 1.4 pμA.





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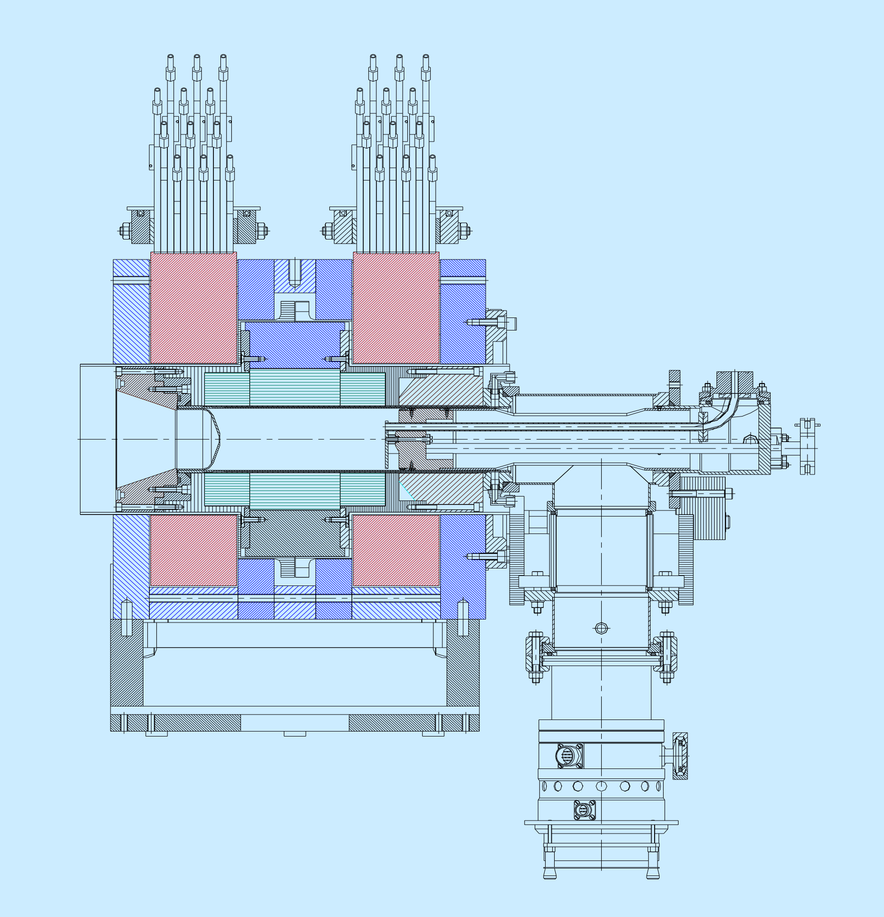
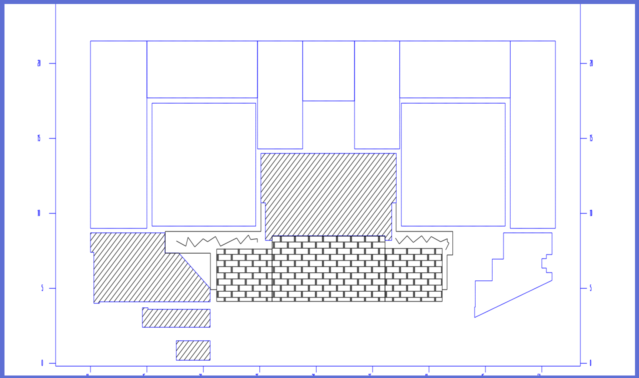
Efficiency of the beam transmission from the ion source to the target at U400.

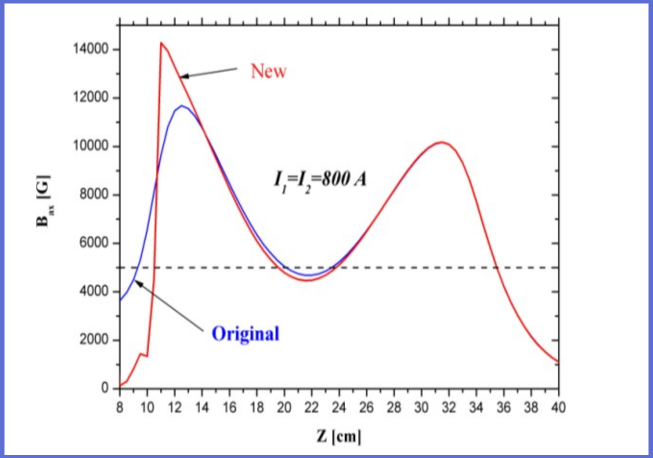
<table>
<tr><th>Measurement point</th><th colspan="2">Beam intensity</th><th>Ion</th><th colspan="5">Transmission</th></tr>
<tr><td>ECR source, after separation</td><td>$1\cdot10^{14}$ pps</td><td>84 μAe</td><td>$^{48}Ca^{5+}$</td><td rowspan="2">32%</td><td></td><td></td><td></td><td rowspan="5">8.5%</td></tr>
<tr><td>Cyclotron center</td><td>$3.5\cdot10^{13}$ pps</td><td>27 μAe</td><td>$^{48}Ca^{5+}$</td><td rowspan="2">81%</td><td></td><td></td></tr>
<tr><td>Radius of beam extraction</td><td>$2.8\cdot10^{13}$ pps</td><td>22 μAe</td><td>$^{48}Ca^{5+}$</td><td></td><td rowspan="2">40%</td><td></td></tr>
<tr><td>Extracted beam (charge exchange method)</td><td>$9.7\cdot10^{12}$ pps</td><td>28 μAe</td><td>$^{48}Ca^{18+}$</td><td></td><td></td><td rowspan="2">82%</td></tr>
<tr><td>Target</td><td>$8\cdot10^{12}$ pps</td><td>23 μAe</td><td>$^{48}Ca^{18+}$</td><td></td><td></td><td></td></tr>
<tr><td>Measurement point</td><td colspan="2">Beam intensity</td><td>Ion</td><td colspan="5">Transmission</td></tr>
</table>

Modernization of the ECR4M

The increase of the discharge chamber Ø from 64 to 74 mm
Higher magnetic field in the injection region. New hexapole. New discharge chamber.
All mechanical parts are produced
Waiting shut-down of U-400 for reconstruction to U-400R







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DECRIS-4

DECRIS-4 – was designed as an injector of multiply charged ions for the U-400 cyclotron, which can be transformed to the charge breeder for the second stage of the DRIBs project .

The design of the magnetic structure of the source is based on the idea of the so-called "magnetic plateau". The axial magnetic field is formed by three independent solenoids enclosed in separated iron yokes. The superposition of the coils and hexapole magnetic fields creates the resonance volume.

Since 2005 the source is in operation at the test bench and is used for the experiments in the solid state physics and for beam development.

This year the source was equipped with the TWT amplifier VZU-6997 (13,75 – 14,5 GHz, 750 W). The first experiments were performed.

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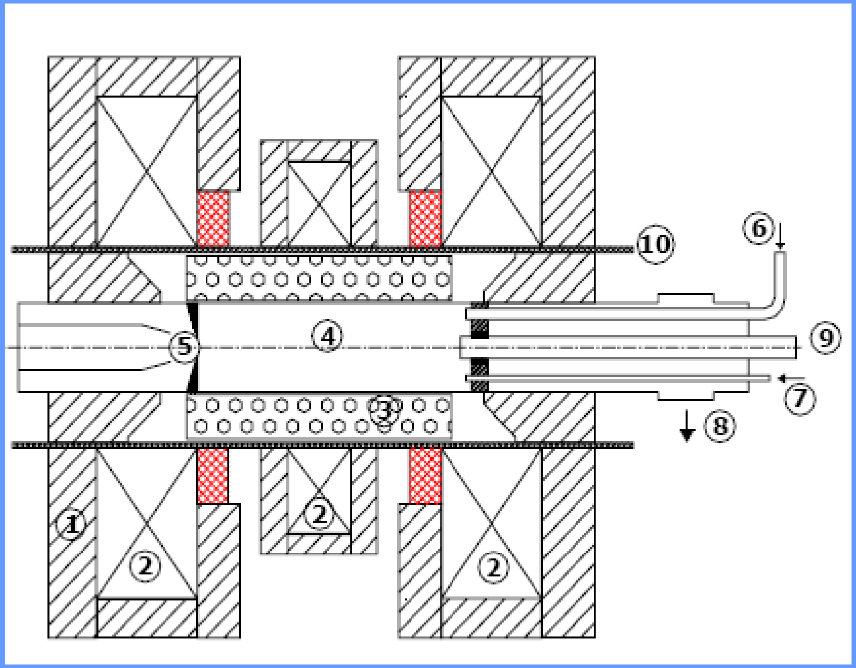
Structure of the DECRIS-4

DECRIS-4

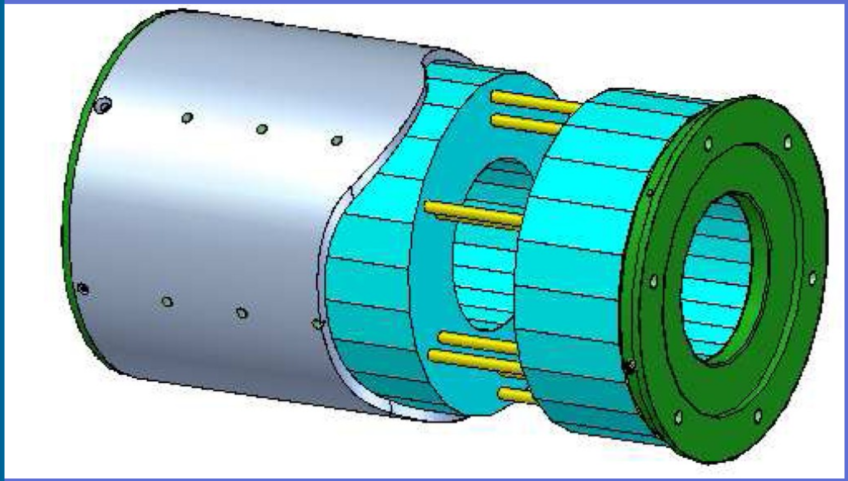


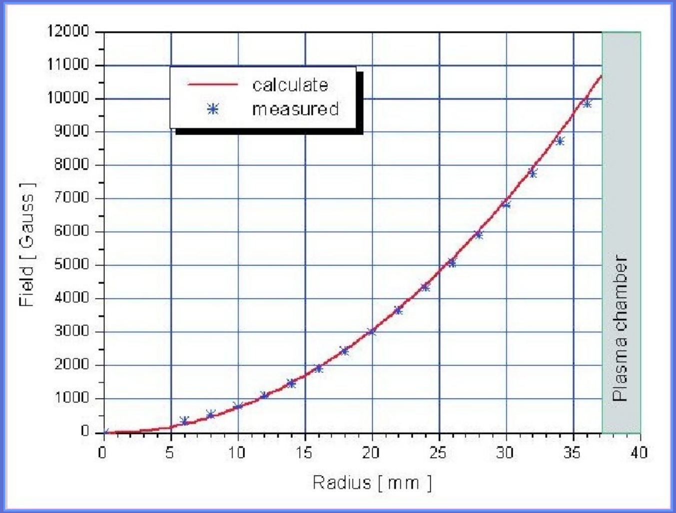
1: Iron yoke. 2: Three independent coils.
3: Hexapole. 4: Plasma chamber.
5: extraction electrodes. 6: UHF input.
7 : Gas feeding. 8: Pumping.
9: Bias electrode. 10: Isolator

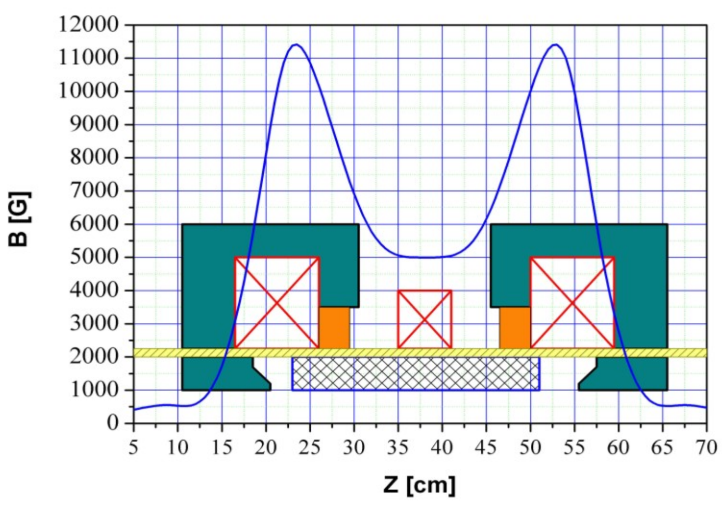
Main parameters	
UHF frequency	14 GHz
B_{inj}	1.29 T
B_{ext}	1.29 T
L_{mirror}	29 cm
Max. coil current	1000 A
Water cooling ΔP	15 bar
Plasma chamber Ø	74 mm
Hexapole field on the wall of plasma chamber	>1.0 T
Max. extraction voltage	30 kV

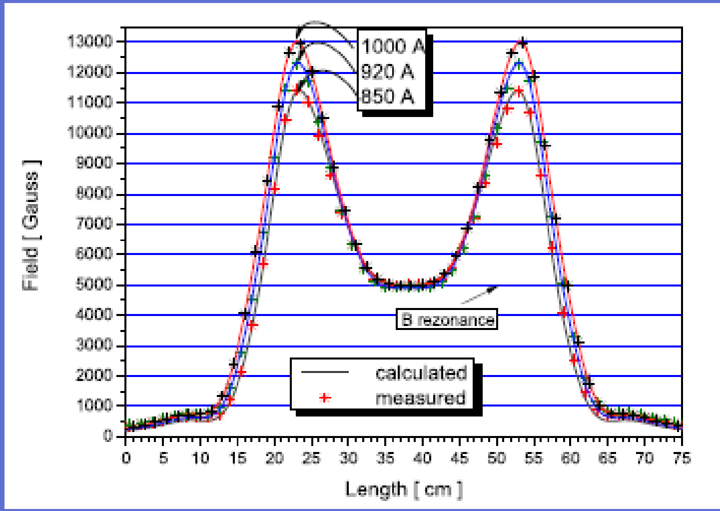
The whole magnetic structure is movable along the axis with respect to the plasma chamber to optimize the plasma electrode position during the source operation.

Magnetic structure of DECRIS-4









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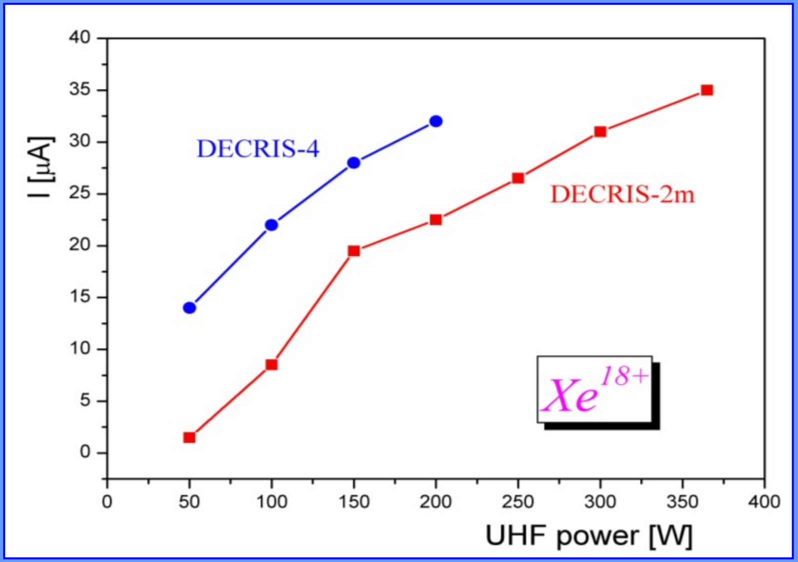
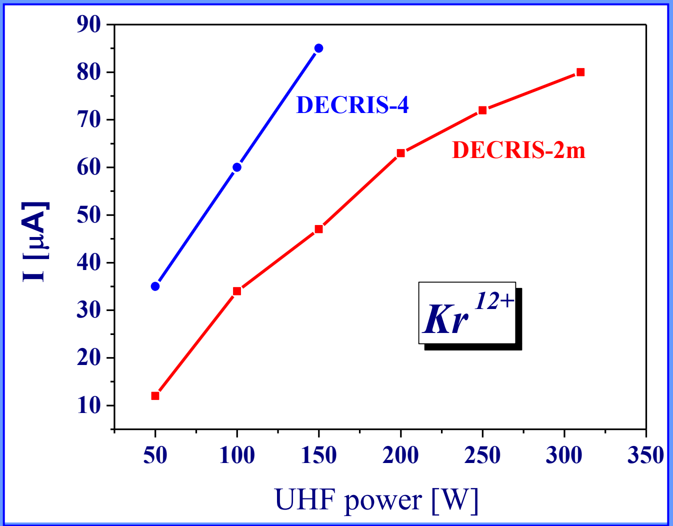
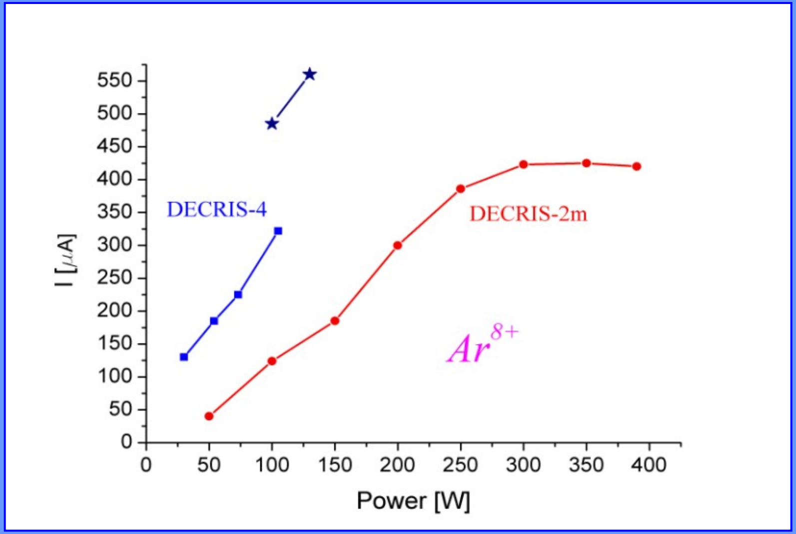
RESULTS

DECRIS-4

Ion	O	Ar	Kr	Xe
6+	400			
7+	80			
8+		400		
9+		220	80	
11+		125	110	
12+		65	85	
15+			35	55
18+				30
20+				25







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Test experiments for production of ^{50}Ti ion beam

Three methods were used:

1. MIVOC (Metal Ions from Volatile Compounds)

   $(CH_3)_5C_5Ti(CH_3)_3$ - (trimethyl)pentamethyl-cyclopentadienyl titanium

   $Ti\{OCH(CH_3)_2\}_4$ - titanium isopropoxide

2. Oven method – TiF_4.
3. Insertion method – Ti rod.

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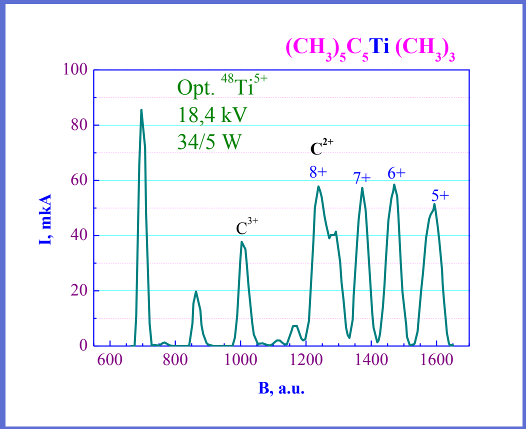

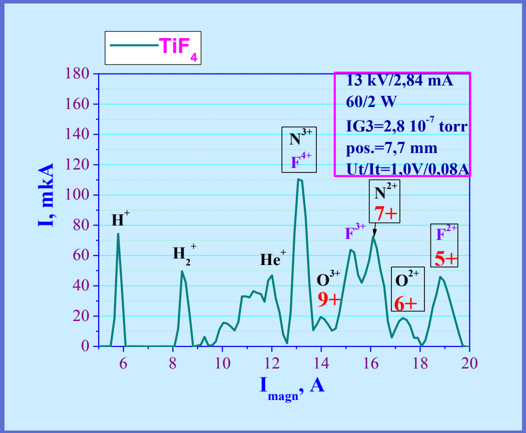

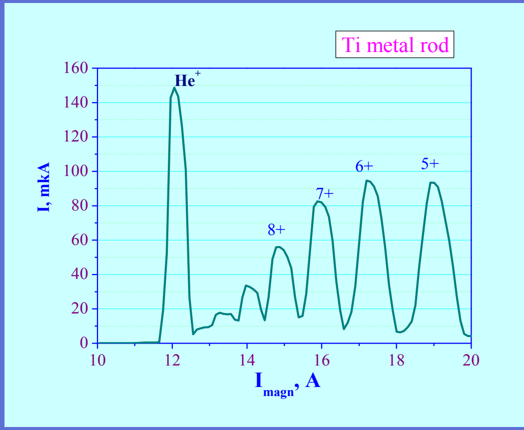

$(CH_3)_5C_5Ti(CH_3)_3$

Stable operation

The intensity is enough for experiments

The synthesis is very complicated and with pure efficiency

$Ti\{OCH(CH_3)_2\}_4$ the current of Ti^{5+} less than 1 μA

Stable mode with current of Ti^{6+} ~10 ÷ 20 μA., then unstable.

Relatively stable mode (current variation ~30 40 %) during 0,5 ÷ 1 hour.

Then current drops to zero, or discharge became uncontrollable.

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DECRIS-SC ion sources.

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ECR ion source with superconducting magnet system

Modernization of CI-100 cyclotron:

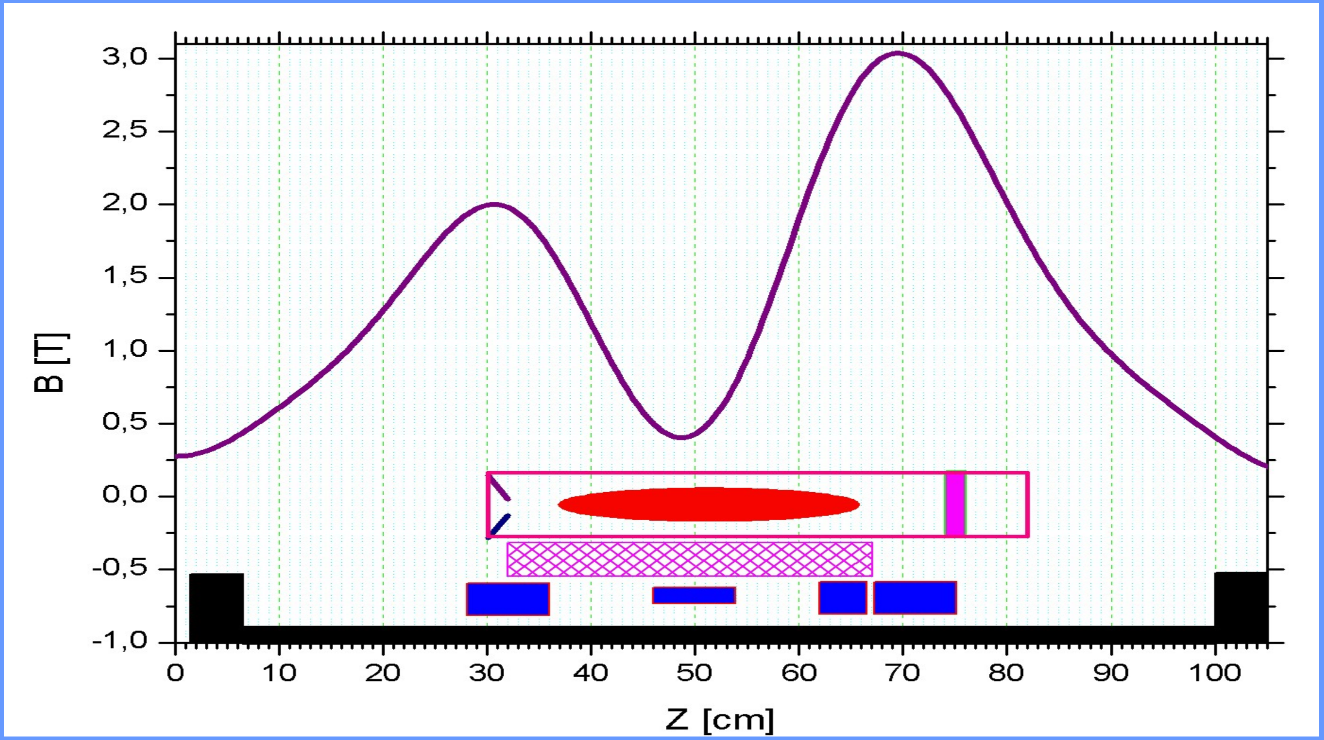
•**accelerated ions - Kr^{15+}, Xe^{22+} energy 1 MeV/n**

Kr^{20+}, Xe^{30+} 2 MeV/n

• **accelerated beam intensity** > 10^{12} pps

• The high enough requirements on charge and intensity of accelerated beams (Kr^{15+}, Xe^{22+}) demand the necessity of using the ion source with the large mirror ratio and a strong magnetic field.

• **"Liquid He free" technology**



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Parameters of DECRIS-SC

UHF frequency	18 28 GHz
Mirror field on the axis: Extraction side Injection side	 2 T 3 T
Mirror to mirror distance	390 mm
Max. coil current	60 A
Radial field at the plasma chamber wall	1.3 T
Plasma chamber internal diameter	74 mm
Max. extraction voltage	30 kV

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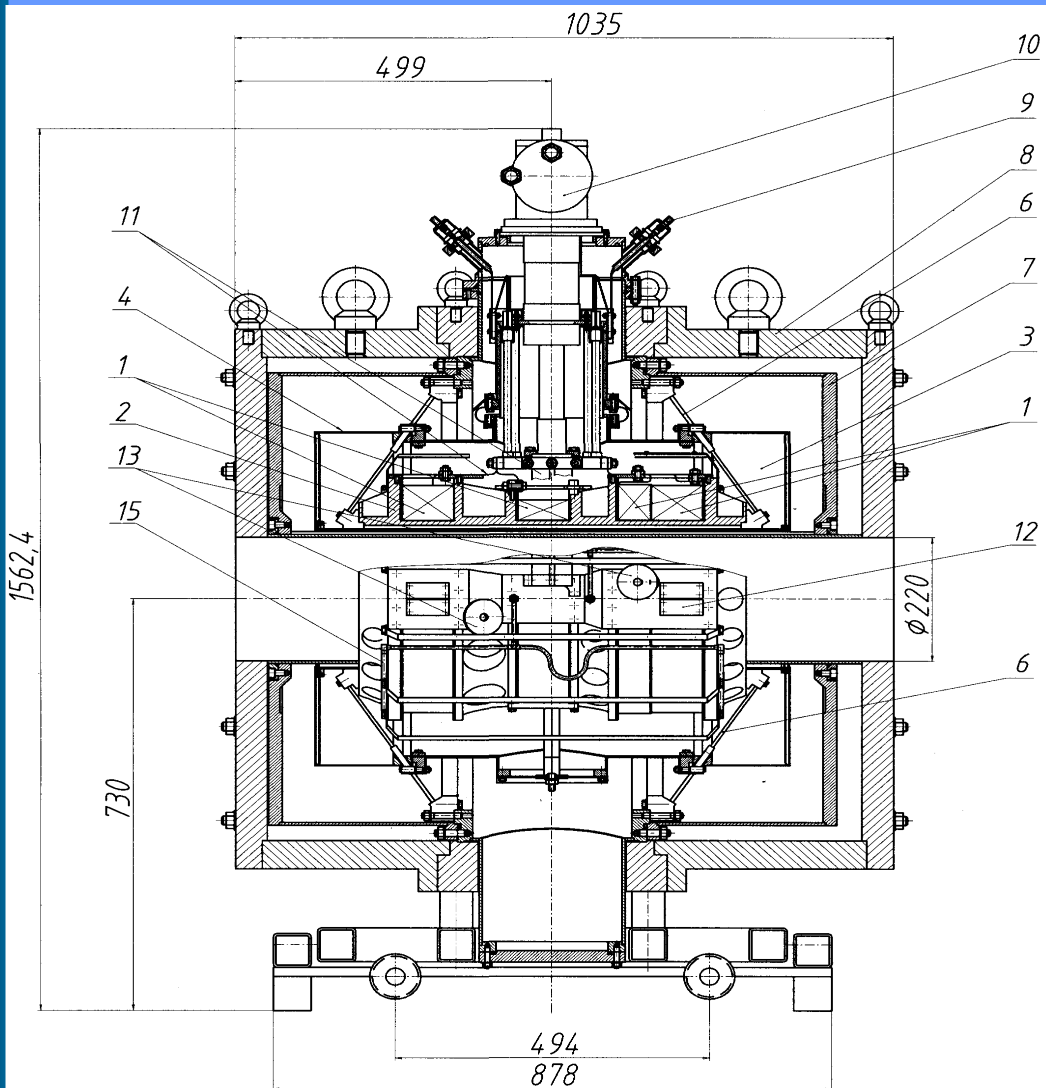
DECRIS-SC



The design of the SC magnet :

1 - superconducting solenoids; 2 - framework of solenoids; 3 - thermal screen; 4 - multilayer screen-vacuum isolation; 6 - support of cold mass; 7 - vacuum casing; 8 - magnetic shield; 9 – current lead; 10 - cryocooler; 11 - heat pipes; 12 - "cold" diodes; 13 - absorbing resistors; 15 - nitrogen heat exchanger.

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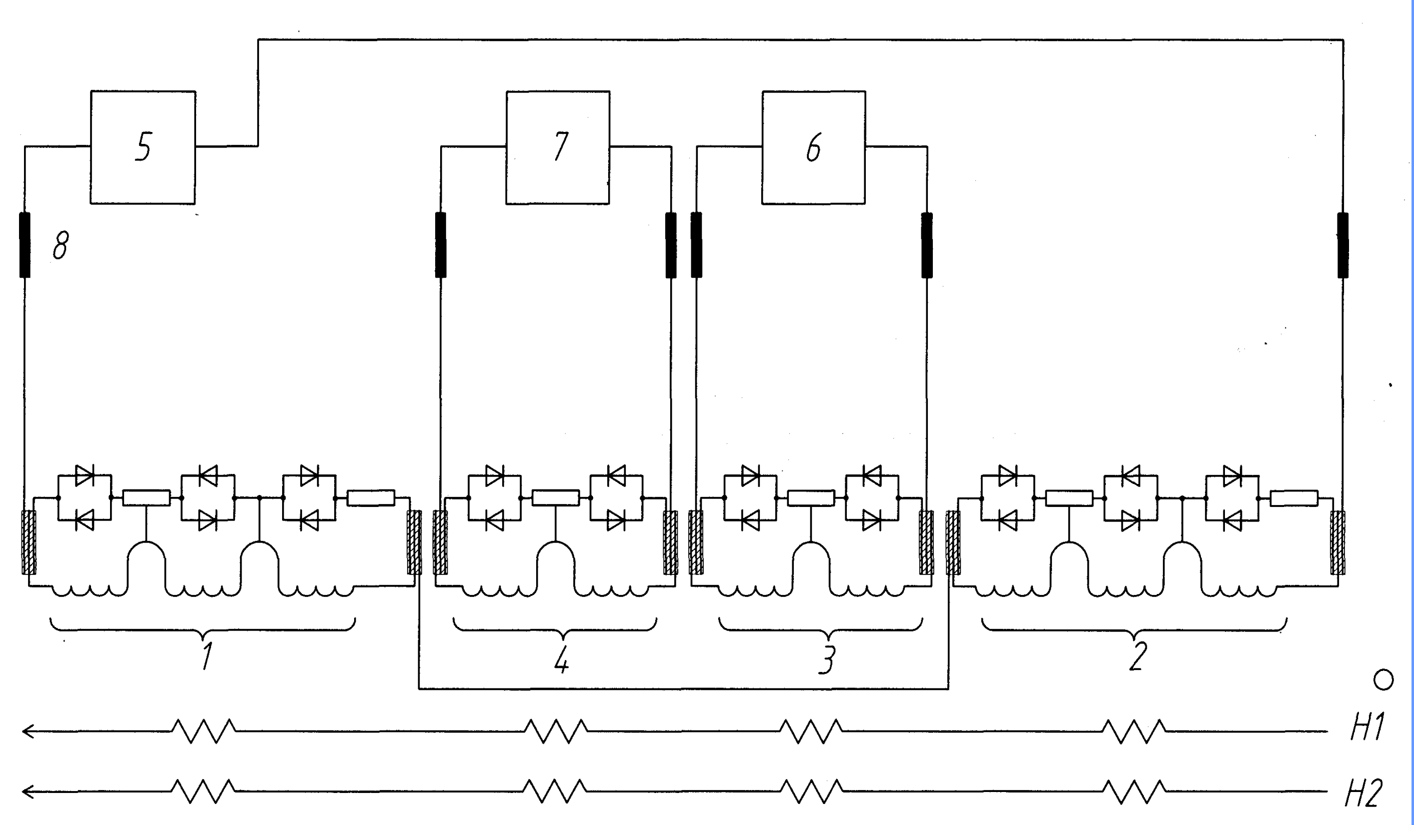
DECRIS-SC

Electrical power supply and safety system:

Passive protection: sectionalization, “cold” diodes and absorbing resistors.
Active protection: three sensor units of the normal zone and eight resistive heaters, installed at the windings.



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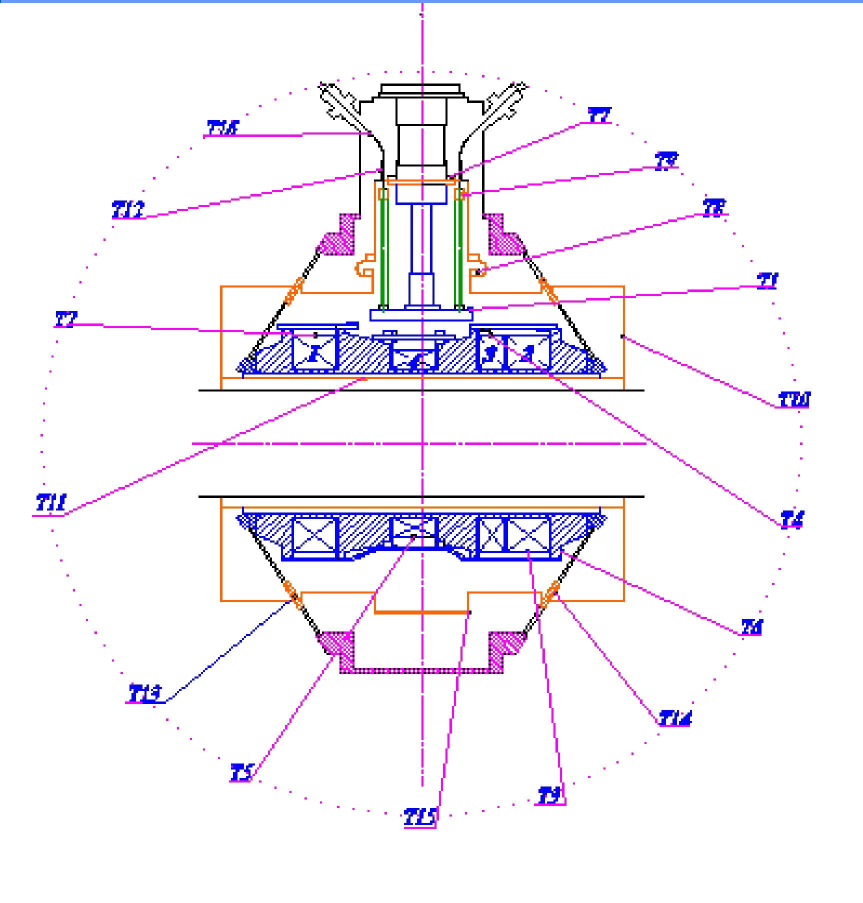
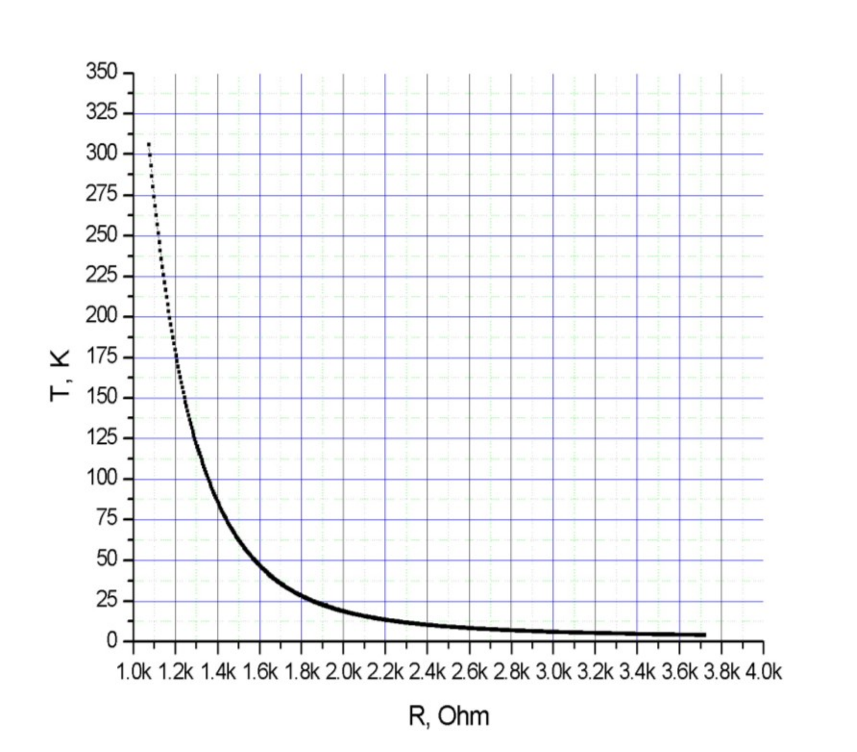
Thermo control:

In the cold zone of the magnet 16 thermometers are located.

Calibrated TVO carbon resistors are used as thermometers





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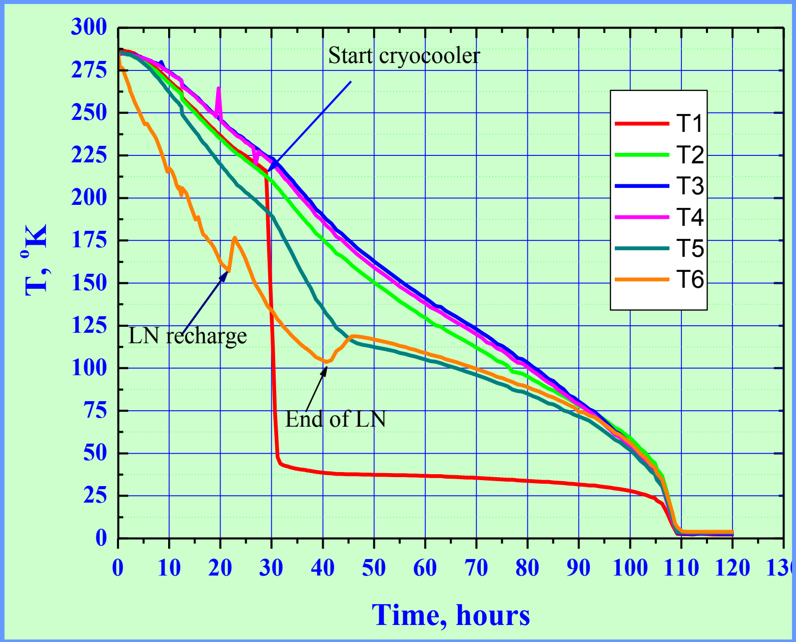
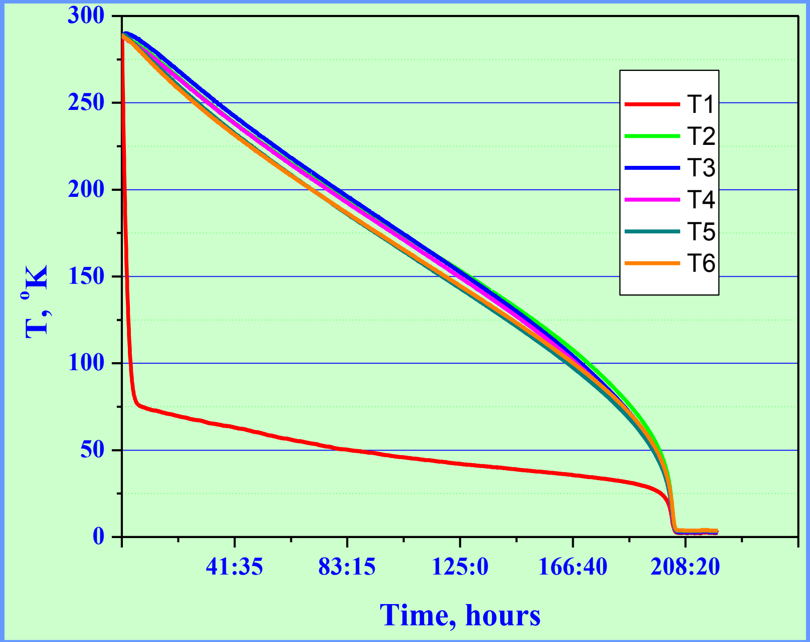
DECRIS-SC

Cooling of the solenoids

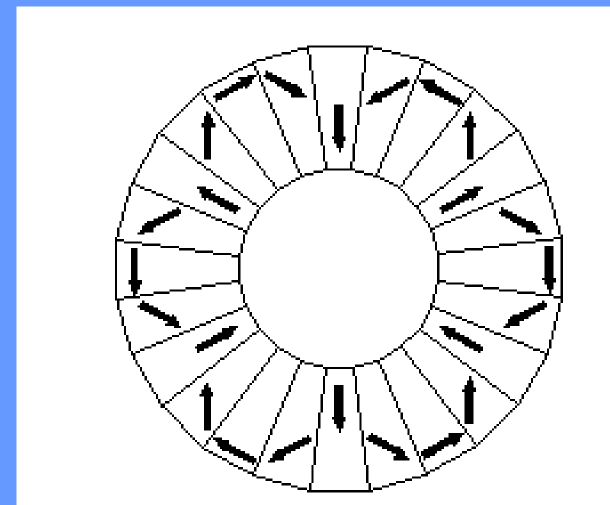


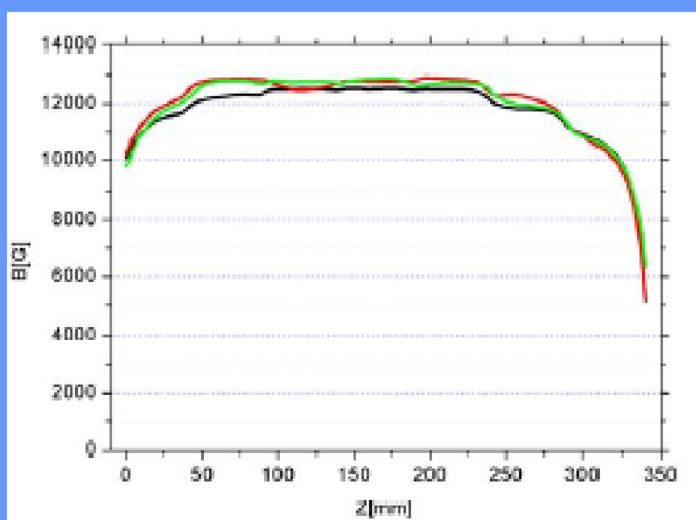


With LN heat exchanger

With cryocooler only

Hexapole design





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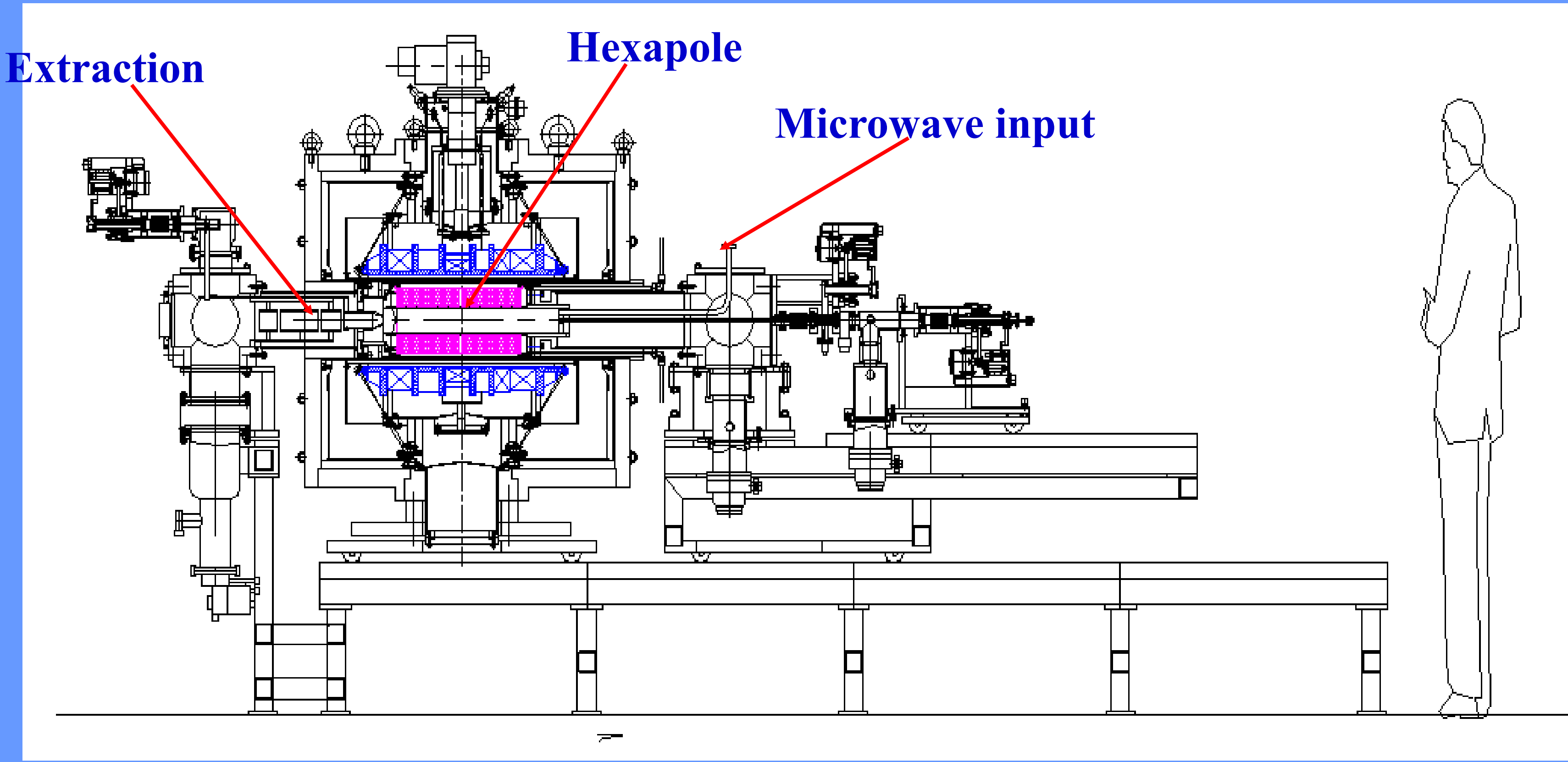
DECRIS-SC

General view of the source



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DECRIS-SC and axial injection system of CI-100 cyclotron

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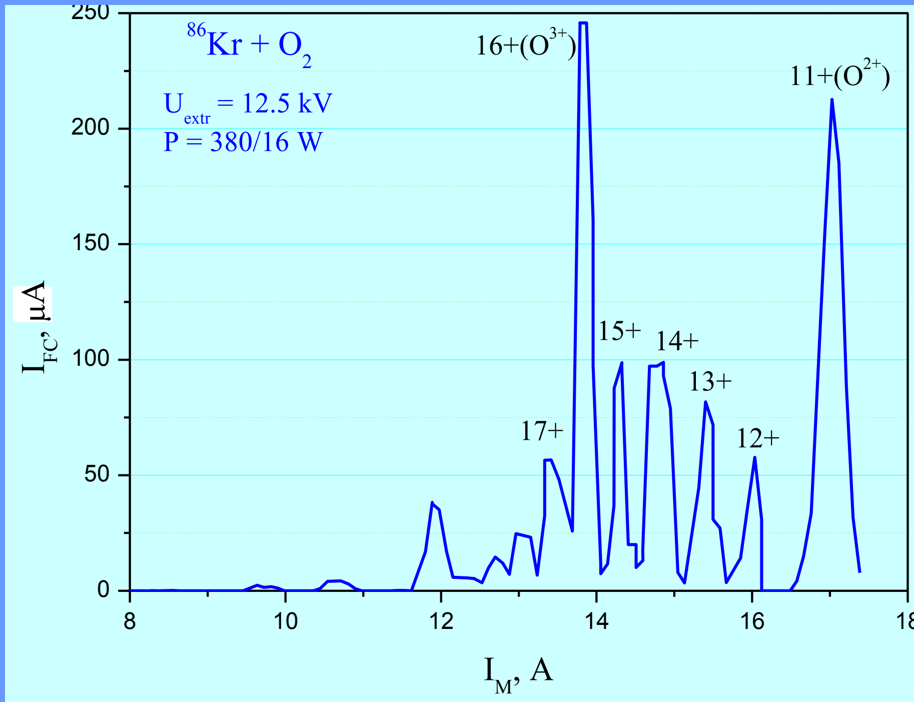
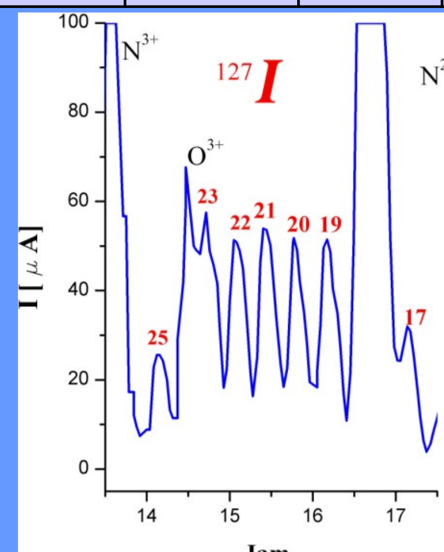
DECRIS-SC



Krypton ion spectrum

Element	A	Z	Target current eμA
Ne	22	+4	0.7
Ar	40	+7	2.5
Fe	56	+10	0.5
Kr	86	+15	3.5
I	127	+22	0.25
Xe	132	+23	3.7
Xe	132	+24	0.6
W	182	+32	0.015
W	184	+31	0.035
W	184	+32	0.017



Since May 2004 the source is in regular operation at the cyclotron for production of polymer membranes and solid state physics

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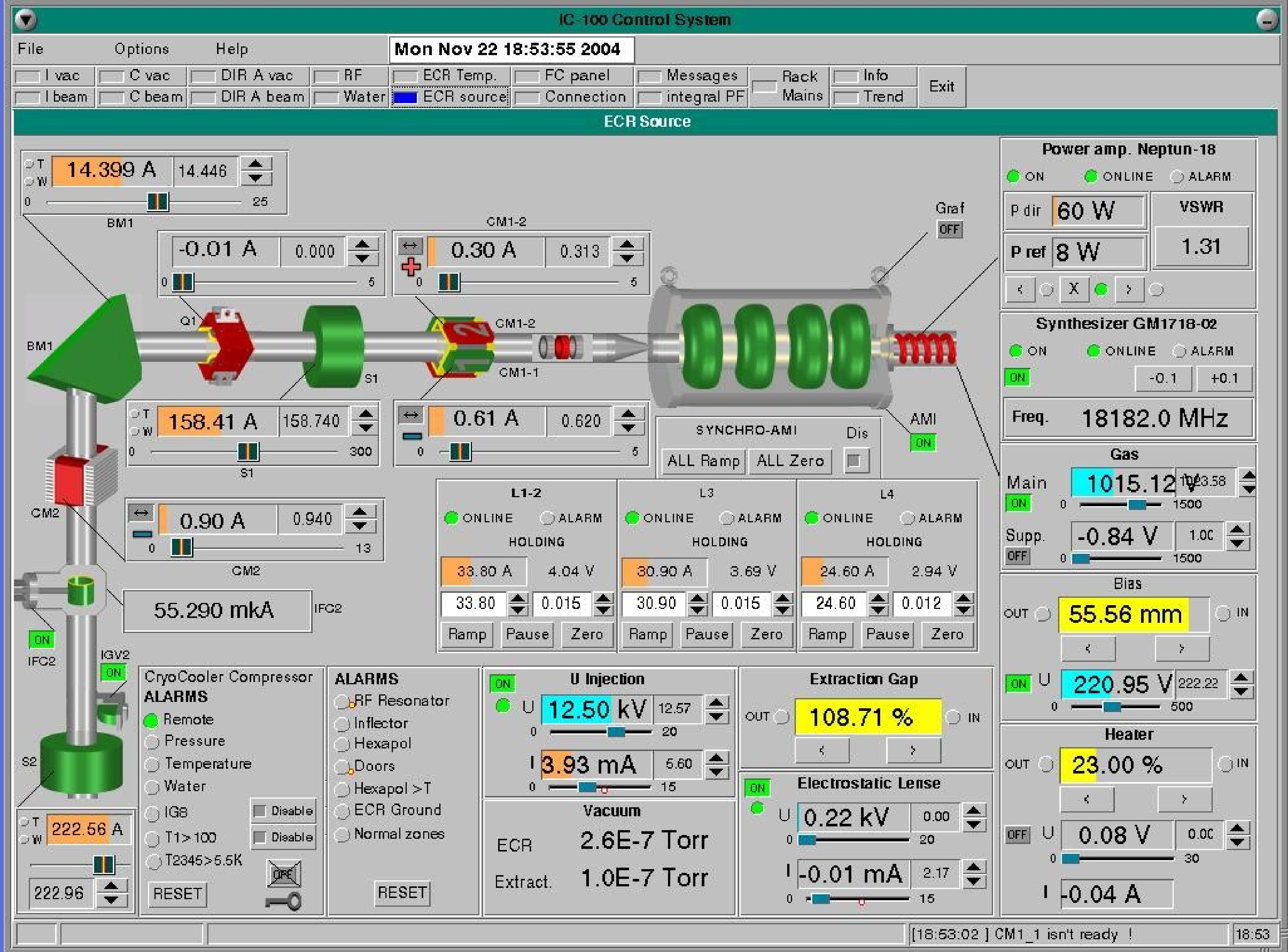
IC-100 Control System
File
Options
Help
Mon Nov 22 18:53:55 2004
I vac
I beam
C vac
C beam
DIR A vac
DIR A beam
RF
Water
ECR Temp.
ECR source
FC panel
Connection
Messages
integral PF
Rack
Mains
Info
Trend
Exit
ECR Source
14.399 A
14.446
BM1
-0.01 A
0.000
CM1-2
0.30 A
0.313
Graf
OFF
Q1
CM1-2
CM1-1
S1
158.41 A
158.740
0.61 A
0.620
SYNCHRO-AMI
Dis
ALL Ramp
ALL Zero
AMI
ON
CM2
0.90 A
0.940
55.290 mkA
IFC2
L1-2
L3
L4
ONLINE
ALARM
HOLDING
33.80 A
4.04 V
30.90 A
3.69 V
24.60 A
2.94 V
Ramp
Pause
Zero
IGV2
S2
222.56 A
222.96
CryoCooler Compressor
ALARMS
Remote
Pressure
Temperature
Water
IG8
T1>100
T2345>5.5K
Disable
RESET
ALARMS
RF Resonator
Inflector
Hexapol
Doors
Hexapol >T
ECR Ground
Normal zones
U Injection
12.50 kV
12.57
3.93 mA
5.60
Vacuum
ECR
2.6E-7 Torr
Extract.
1.0E-7 Torr
Extraction Gap
108.71 %
Electrostatic Lense
0.22 kV
-0.01 mA
Power amp. Neptun-18
P dir
60 W
P ref
8 W
VSWR
1.31
Synthesizer GM1718-02
Freq.
18182.0 MHz
Gas
Main
1015.12 V
Supp.
-0.84 V
Bias
55.56 mm
220.95 V
222.22
Heater
23.00 %
0.08 V
-0.04 A
[18:53:02] CM1_1 isn't ready !
18:53

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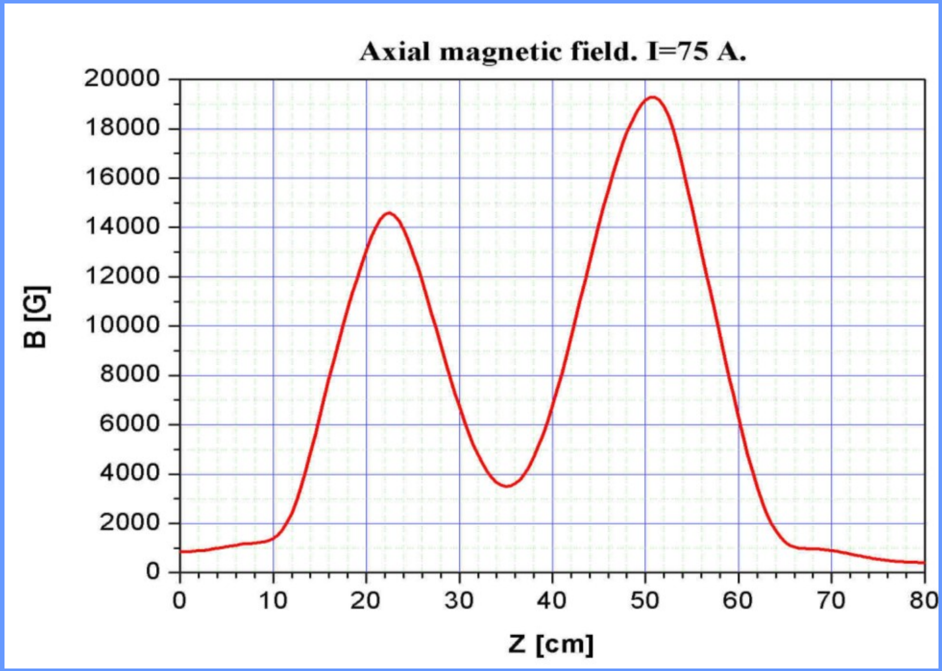
DECRIS-SC2 ion source for U-400M cyclotron

The main goal of the DECRIS-SC2 source is the production of more intense beams of heavy ions in the mass range heavier than Ar.

Table of main parameters.

Operating frequency	14 GHz
UHF power range	50 700 W
Axial magnetic field (injection/extraction)	1.9 / 1.4 T
Coils power consumption	10 kW (cryocooler)
Coil current	75 A
Radial magnetic field	1.0 T
Plasma chamber diameter	74 mm
Source diameter / length	690 / 570 mm
Source weight	~ 700 kg



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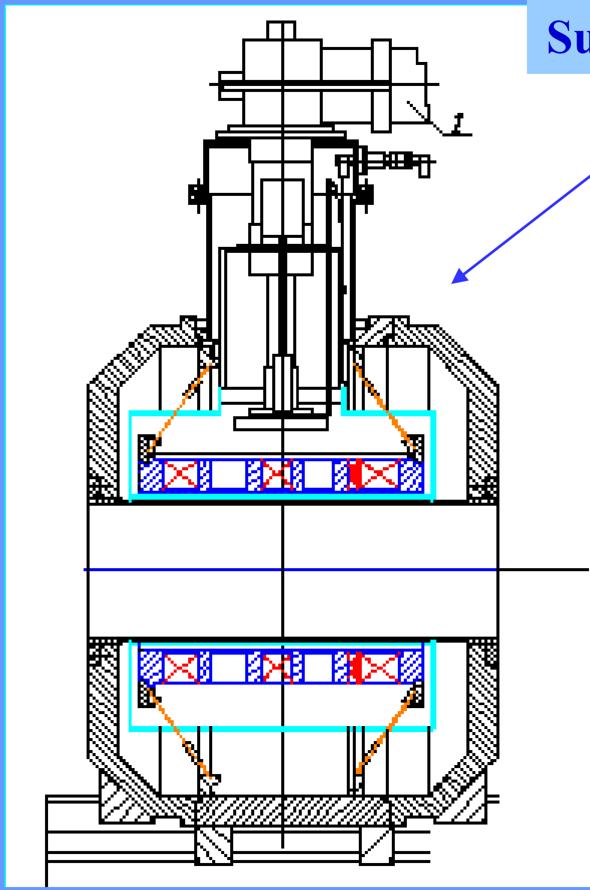
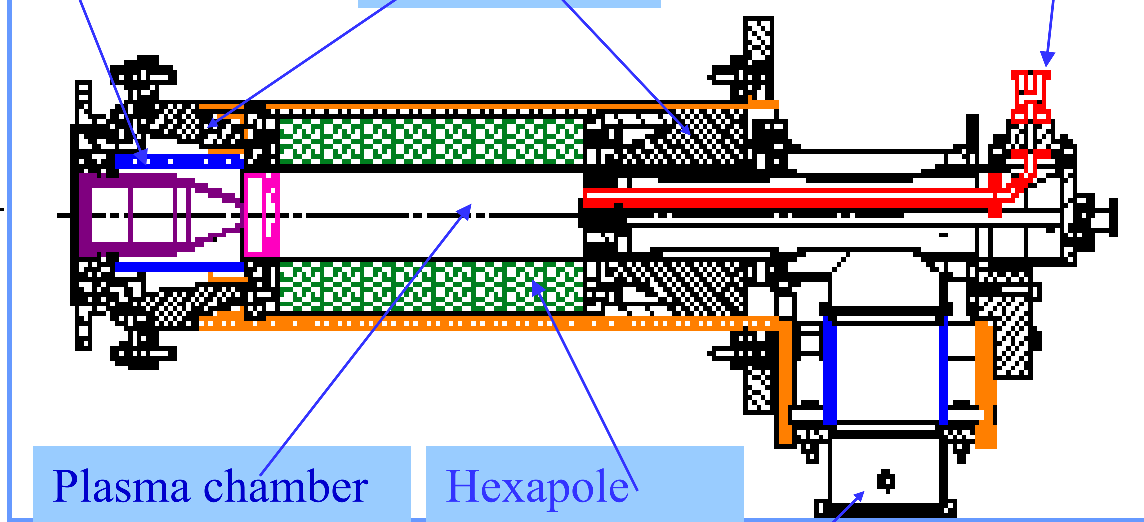
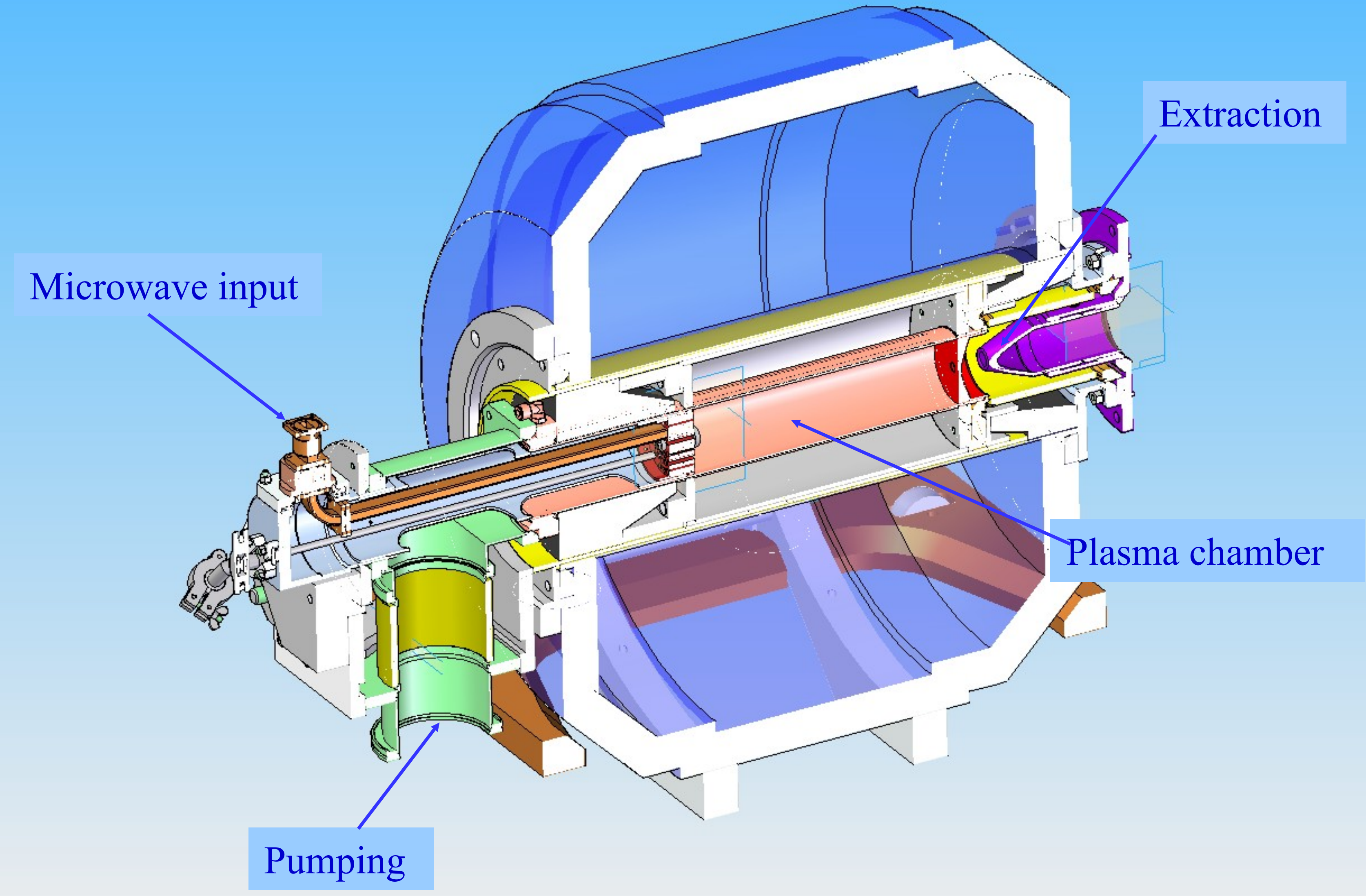
DECRIS-SC2

DECRIS-SC2 is the compact version of the "liquid He free" superconducting ion source. The axial magnetic field is created by superconducting coils and iron plugs. The radial magnetic field is formed by permanent magnet hexapole.





DECRIS-SC2



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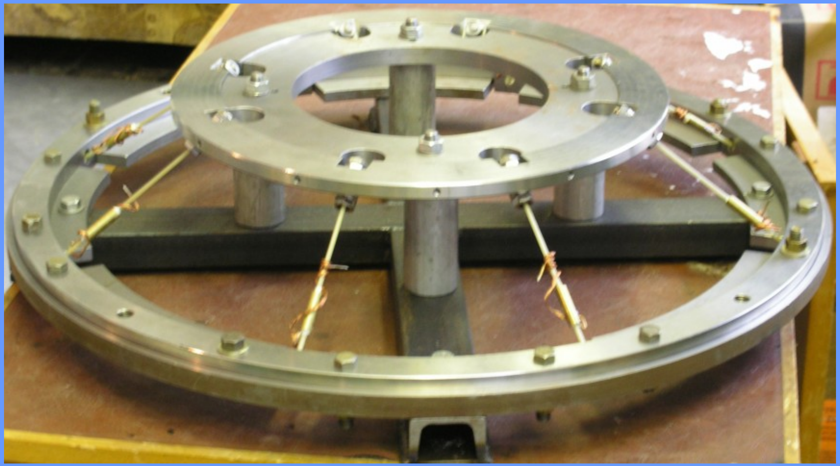
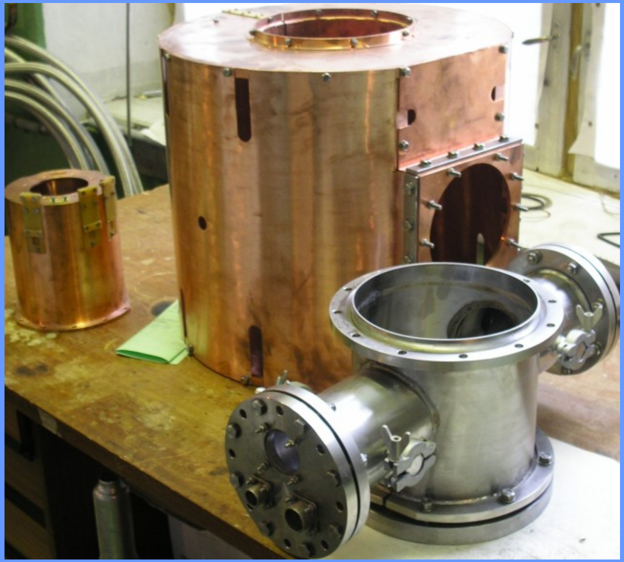
Components of DECRIS-SC2

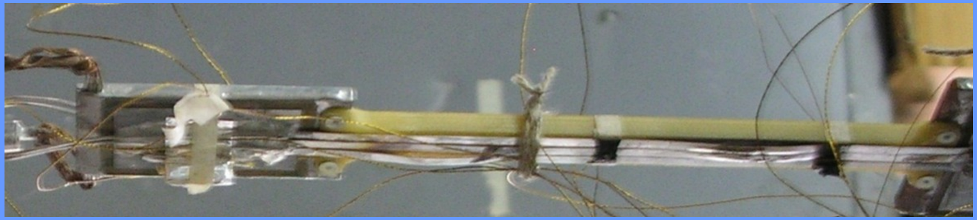
Superconducting solenoid



Cold mass support



Thermal screen



HTSC current lead

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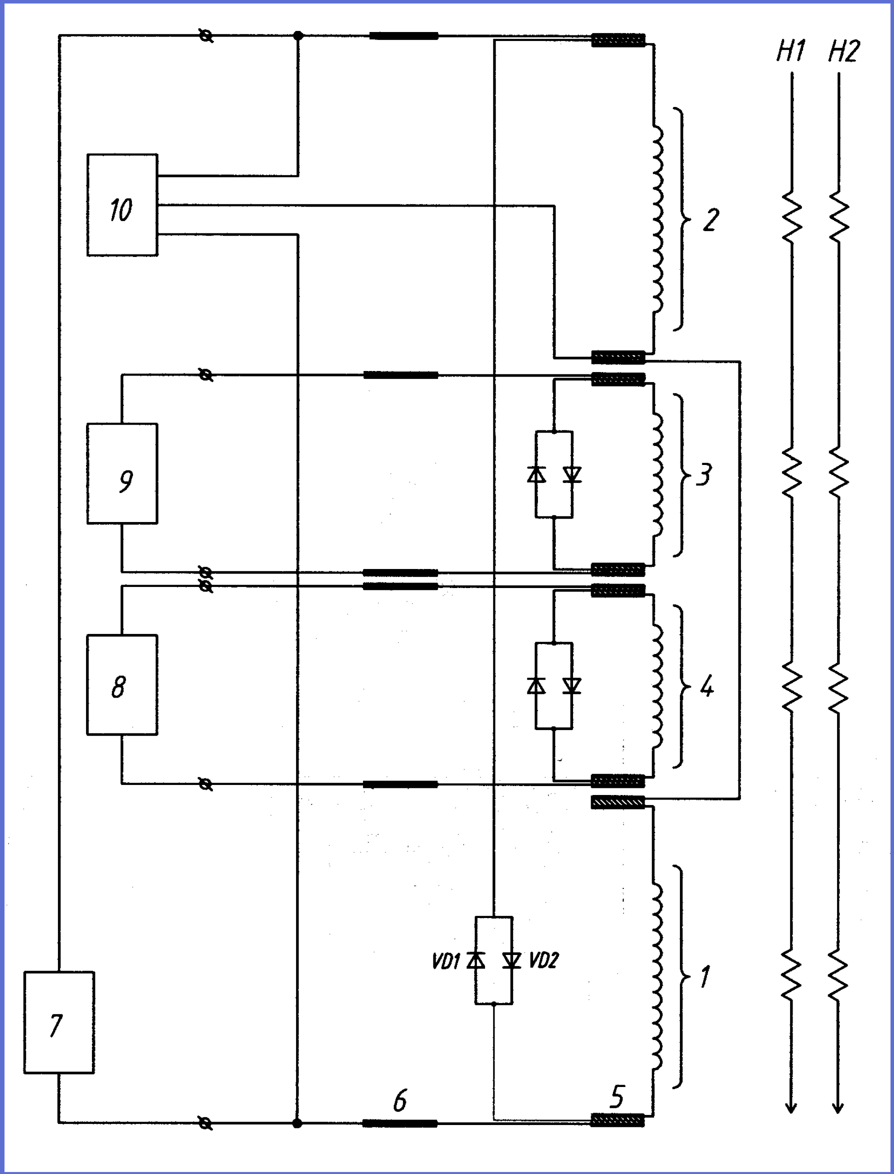
An electrical circuit of the power supply and protection of solenoids:



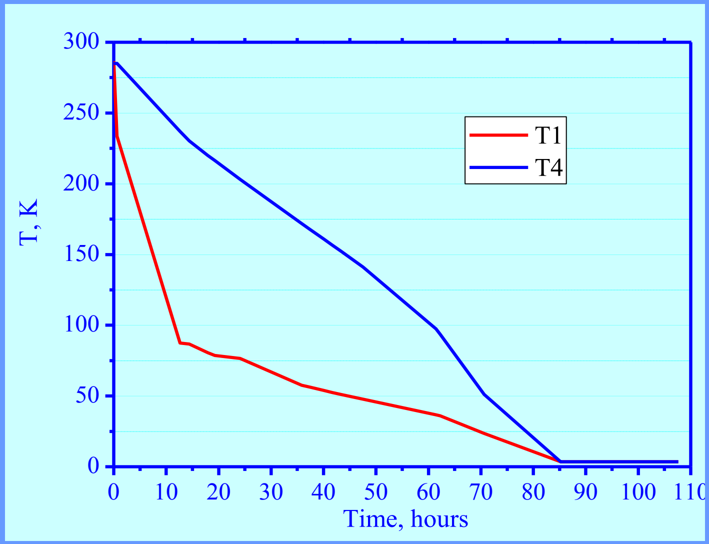
1, 2, 3, 4 – windings;

5 – electrical and thermal contacts of the windings ends, current leads conductors and diodes;

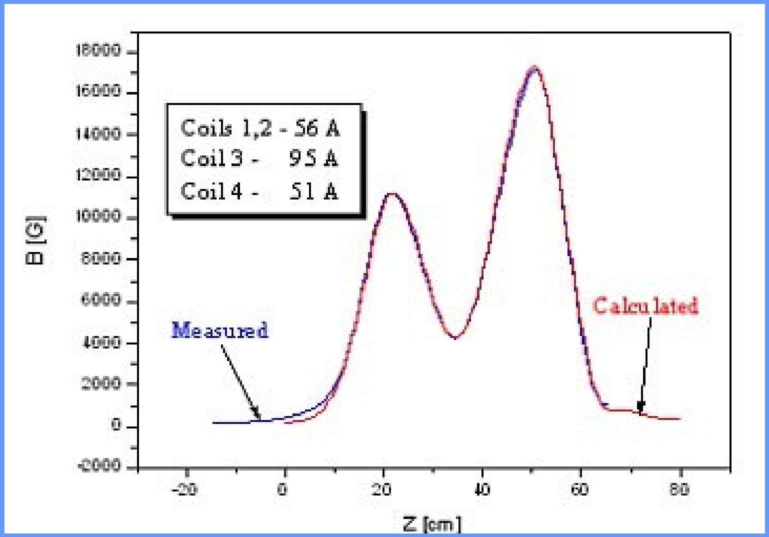
6 - HTSC current leads; 7,8,9 - current sources of the windings;

10 – quench detector; H1, H2 – heaters; VD – “cold” diodes.

Tests of the superconducting magnet system

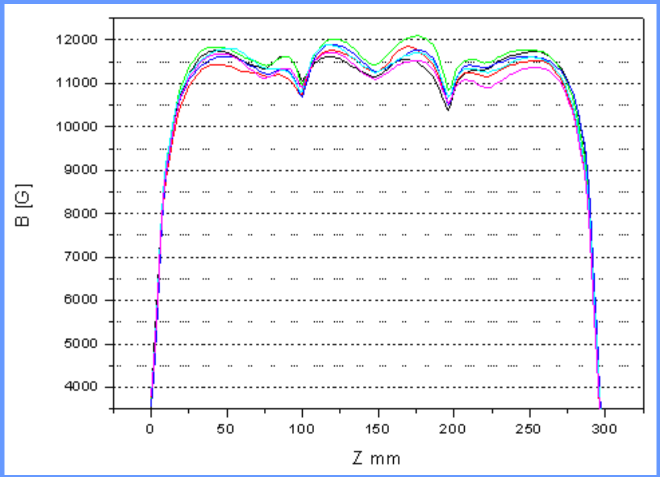


Cooling

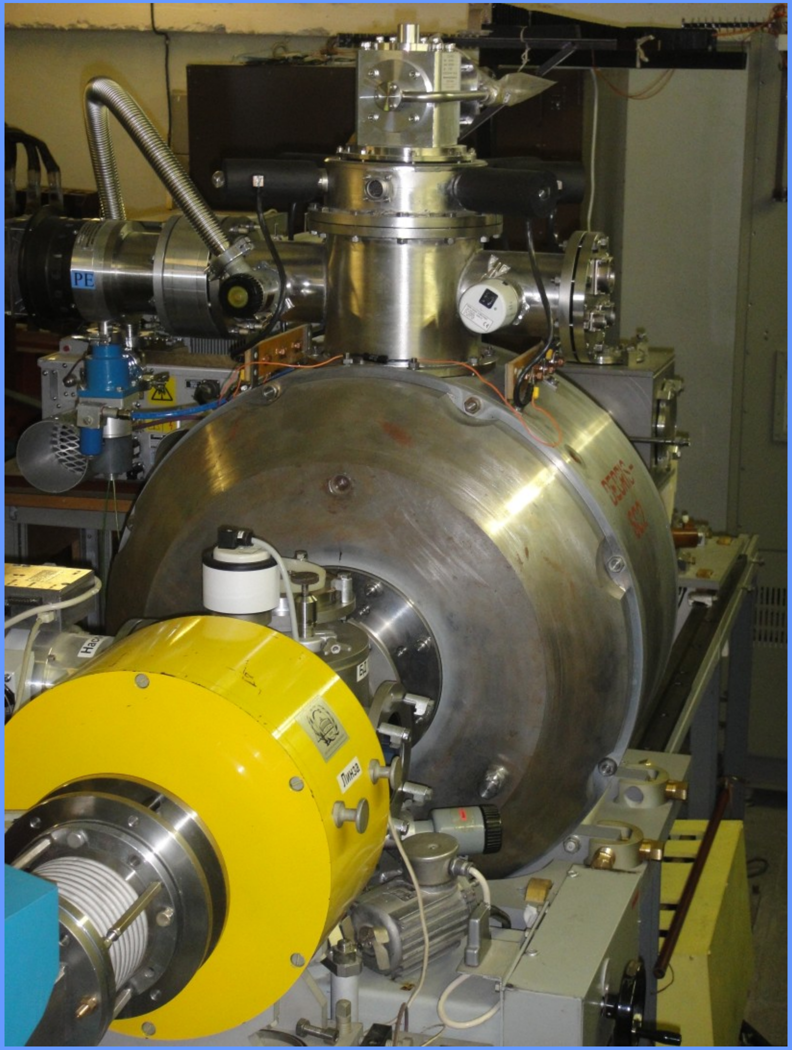


Axial magnetic field measurement

Hexapole magnetic field measurement



DECRIS-SC2



Power supply and control system of SC magnet

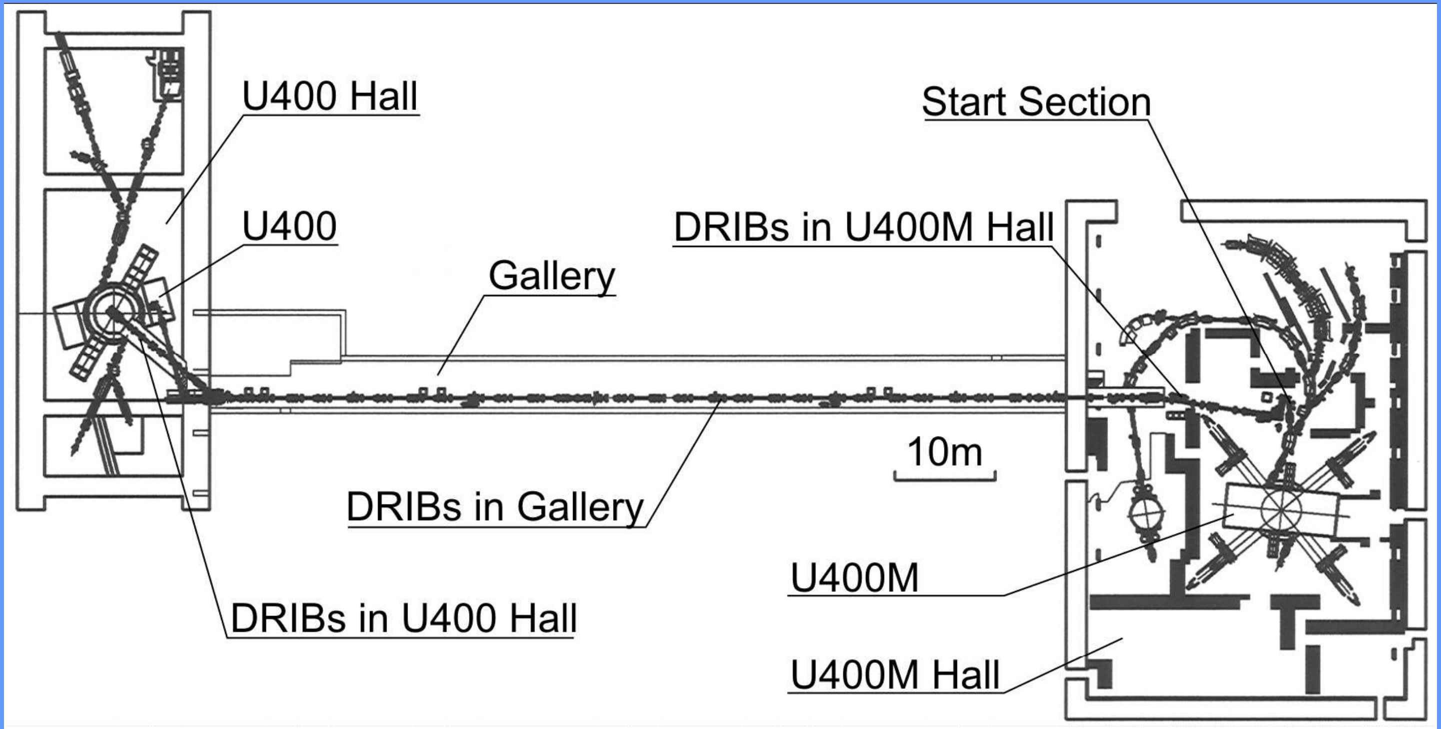
The superconducting magnet system passed the full test.

The source is assembled and installed at the test bench.

Mechanical problems in coupling the source with the test bench extraction box.

DRIBs (Dubna Radioactive Ion Beams) project

- **First phase – production and acceleration of ^{6}He и ^{8}He beams.**
- Second phase – *production and acceleration of fission products (^{132}Sn).*



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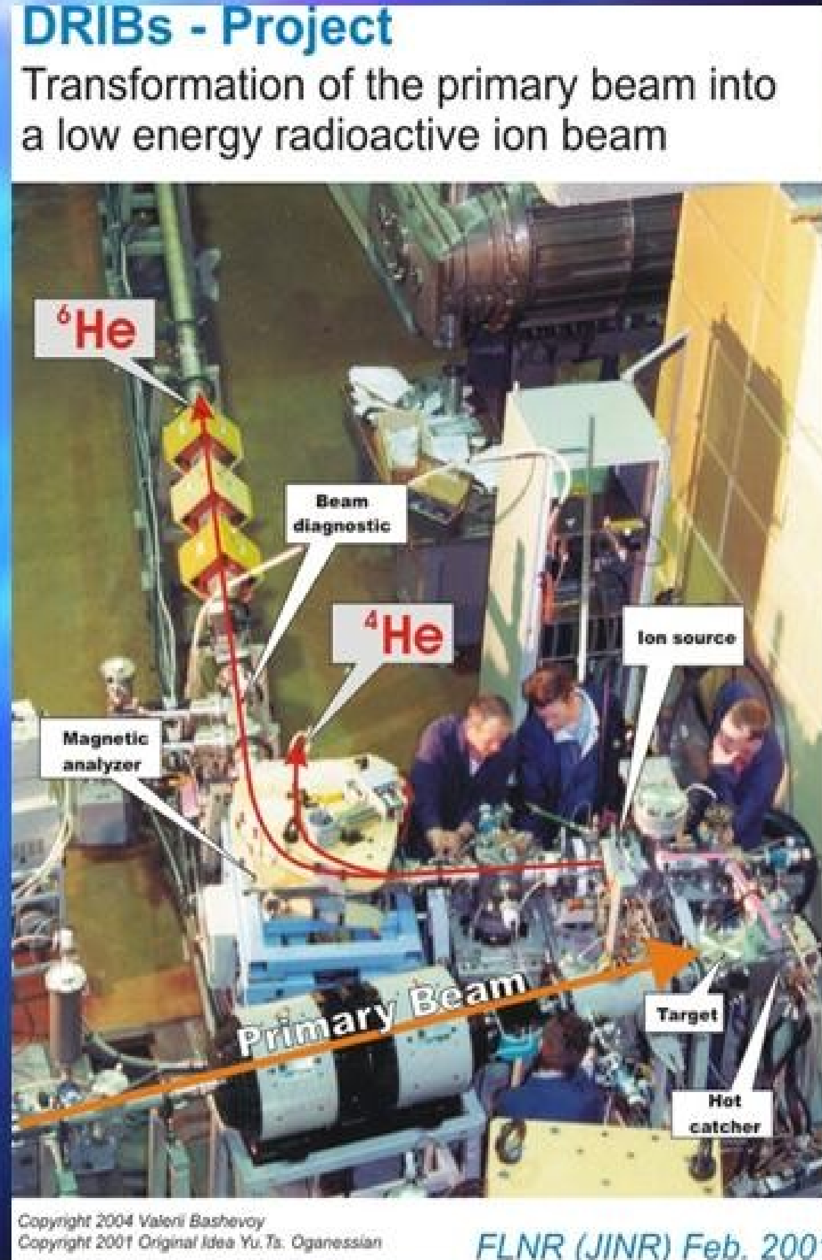
Dubna



DRIBs - Project
Transformation of the primary beam into a low energy radioactive ion beam
^{6}He
Beam diagnostic
^{4}He
Ion source
Magnetic analyzer
Primary Beam
Target
Hot catcher
Copyright 2004 Valerii Bashevoy
Copyright 2001 Original Idea Yu.Ts. Oganessian
FLNR (JINR) Feb. 2001

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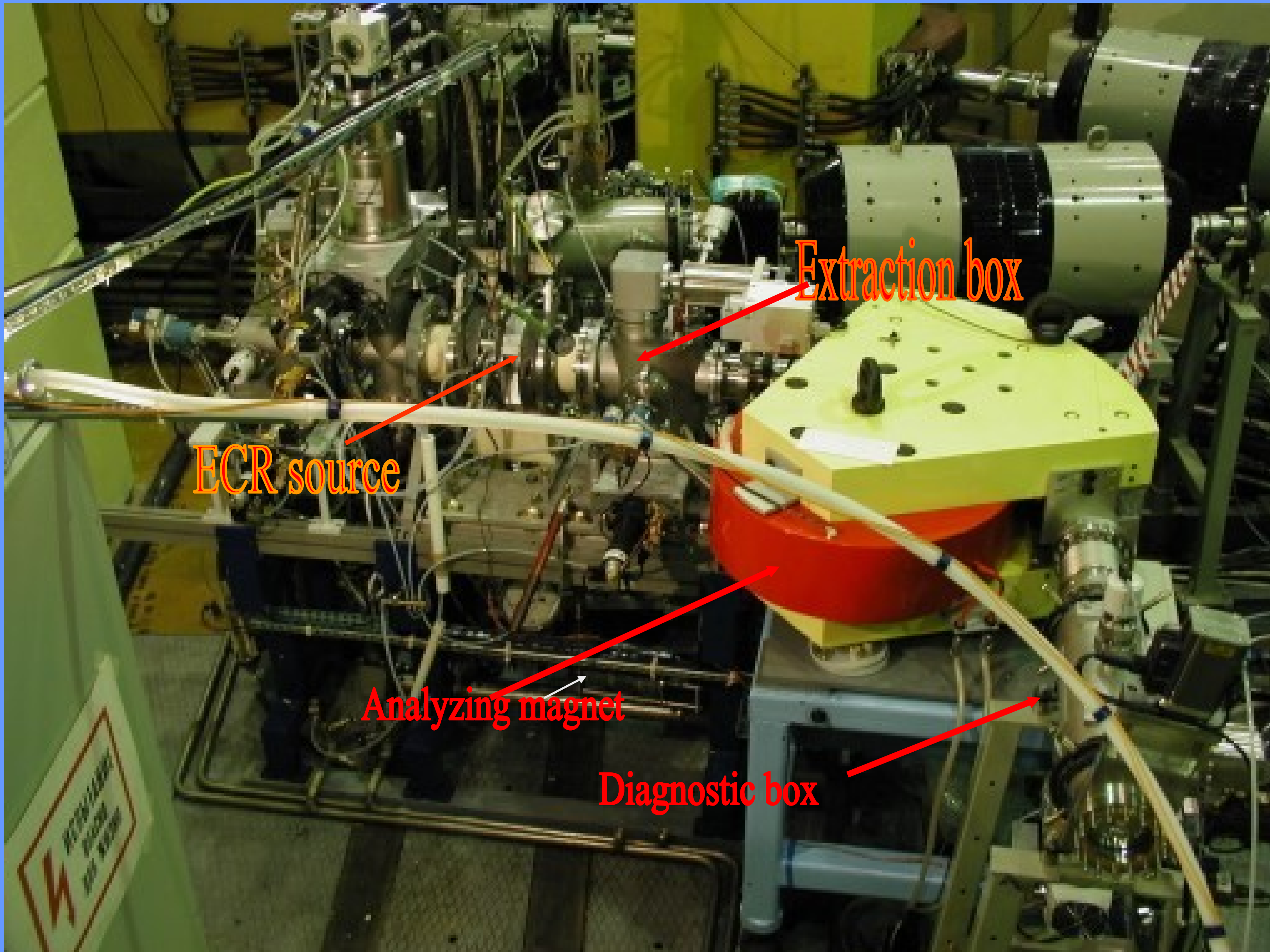
Extraction box
ECR source
Analyzing magnet
Diagnostic box

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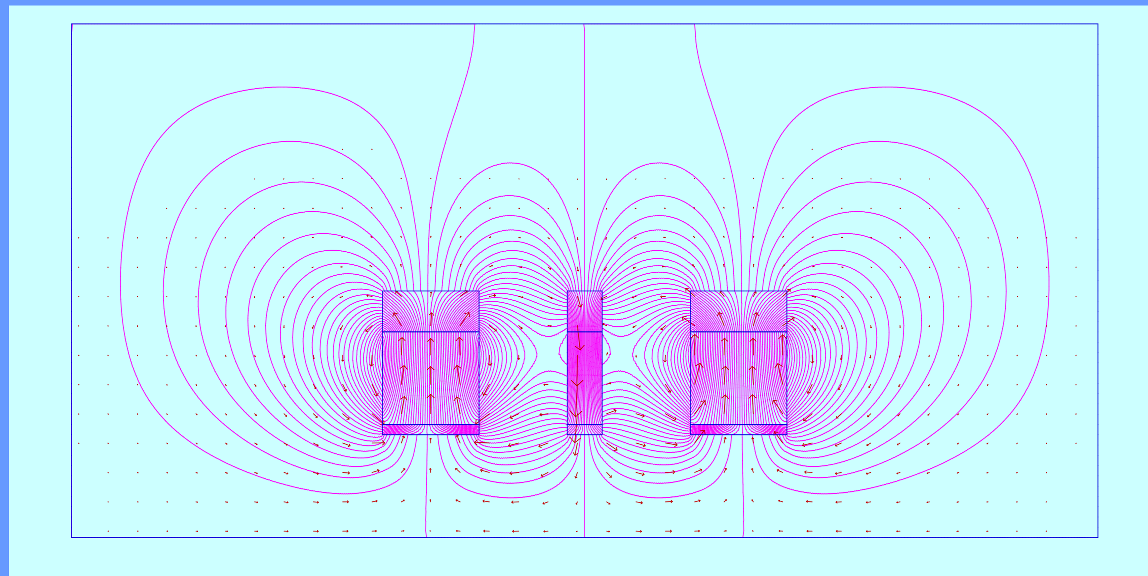
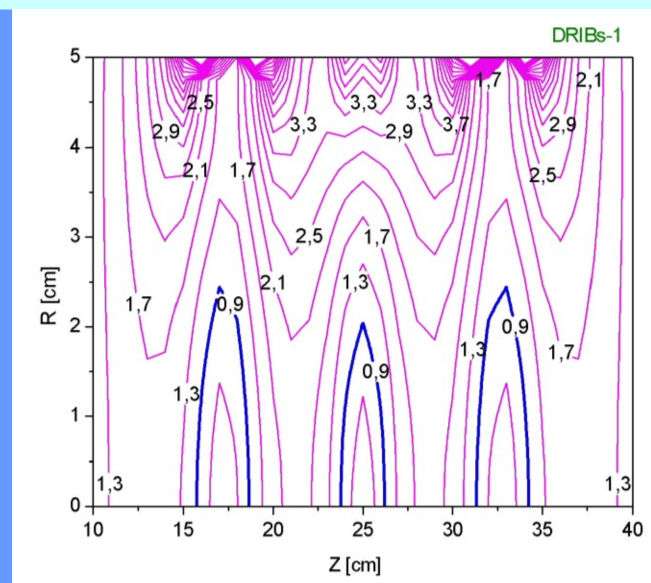
Magnetic structure of ECR ion source for DRIBs
(operating frequency 2.45 GHz)





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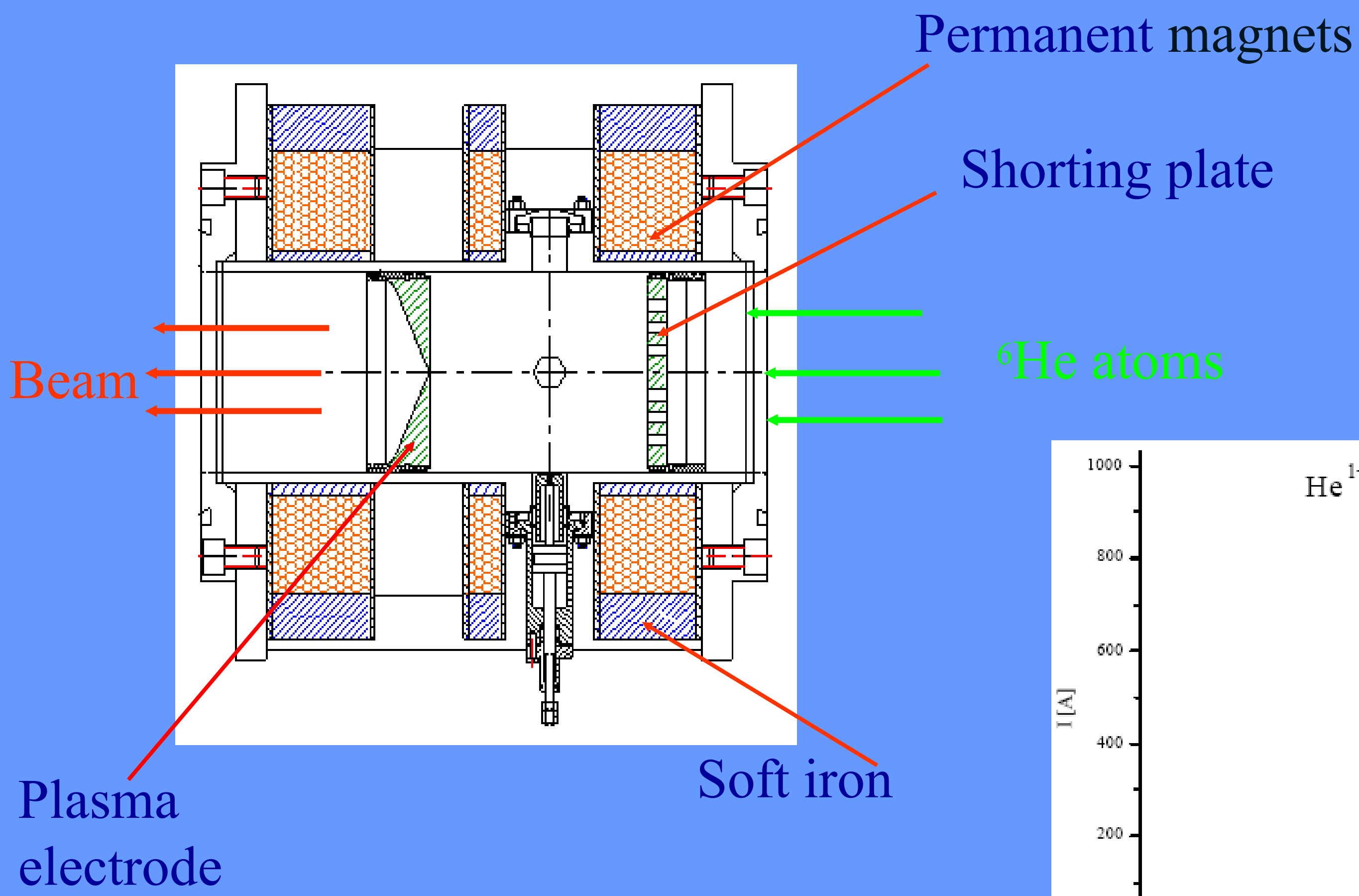
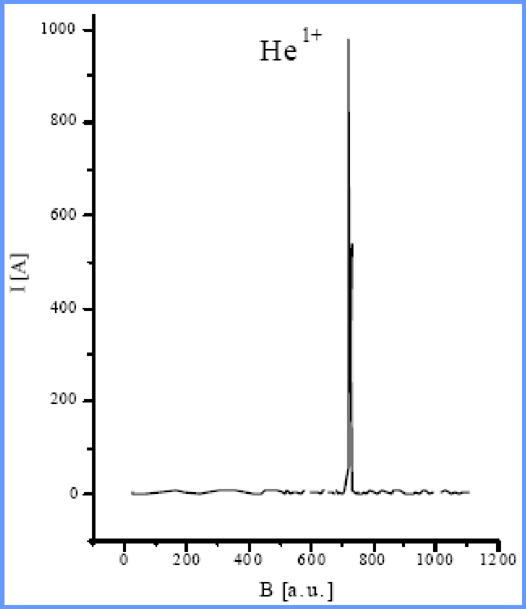
ECR ion source for DRIBs





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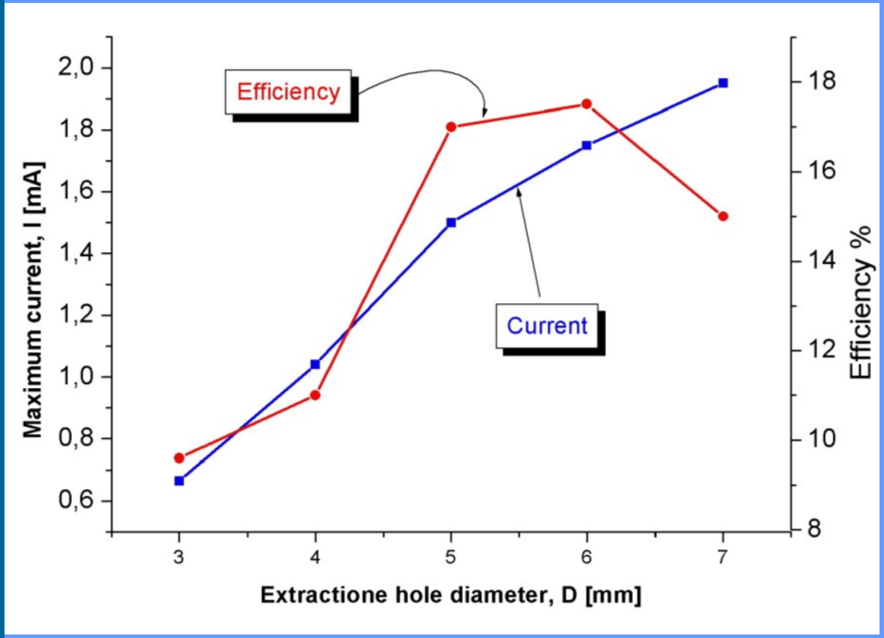
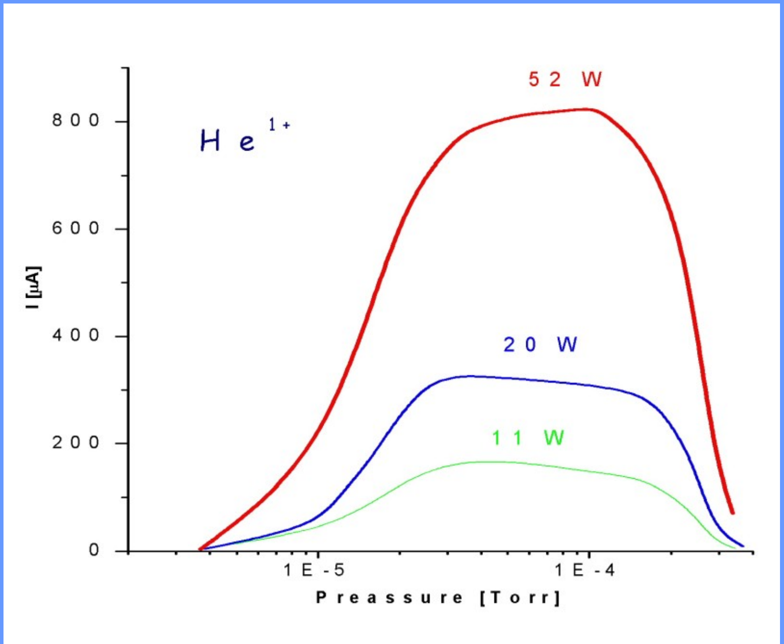
ECR ion source for DRIBs





Maximum extracted $^{4}He^{1+}$ current and global efficiency versus the diameter of the extraction hole.

Efficiency for Ar and Kr ≥ 80%

Intensity of ^{7}Li primary beam
U-400M

3 pμA

Intensity of ^{6}He accelerated beam
U-400

$5\ 10^{7}$ pps

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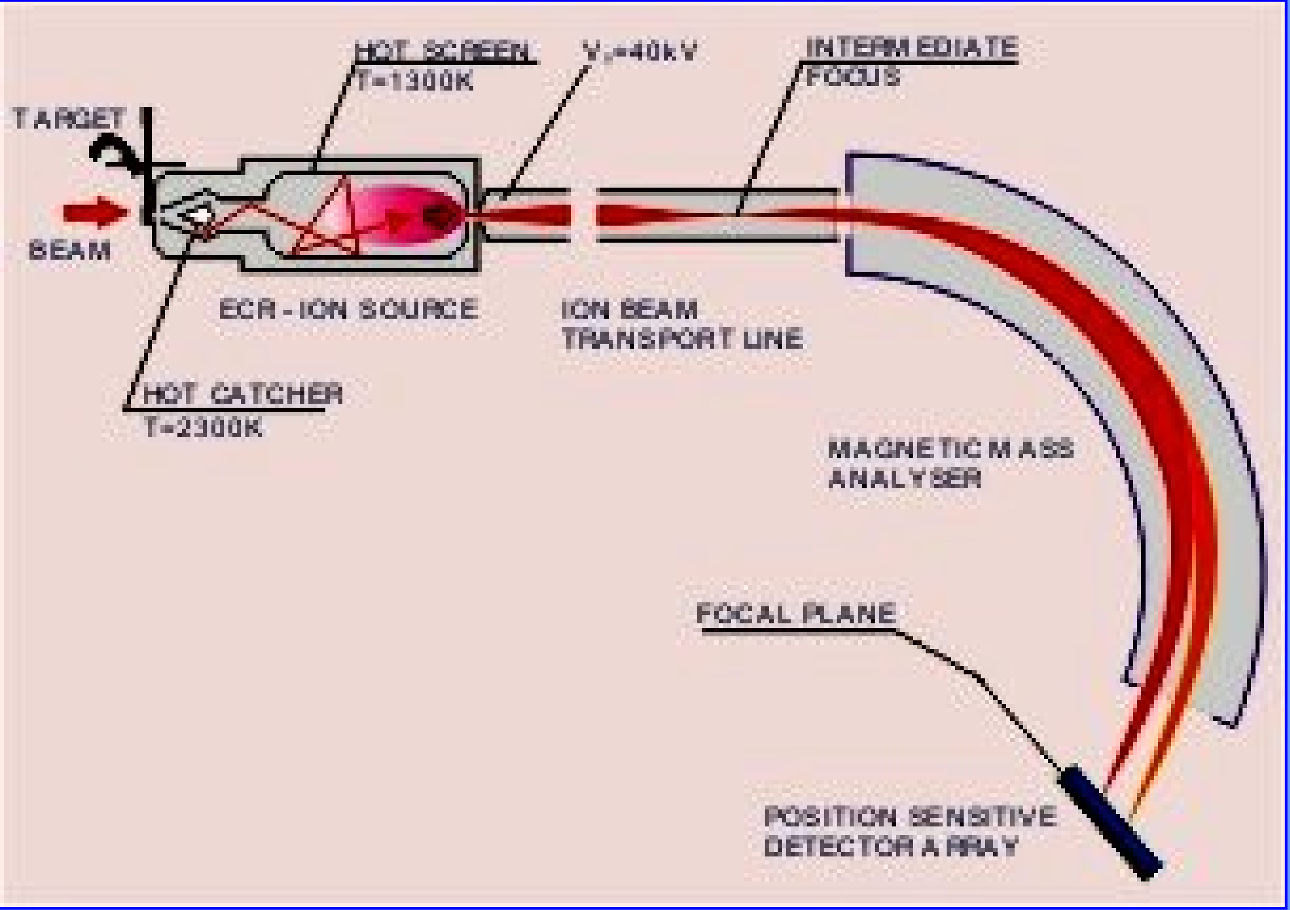
MASHA (Mass Analyzer of Super Heavy Atoms)

Mass identification of super heavy nuclei with a resolution better than 1 amu at the level of 300 amu.

Synthesized in nuclear reactions nuclides are emitted from an ECR ion source at energy E = 40 kV and charge state Q = +1. The set up can work in the wide mass range from A~20 to A 500, mass acceptance ±2.8%.



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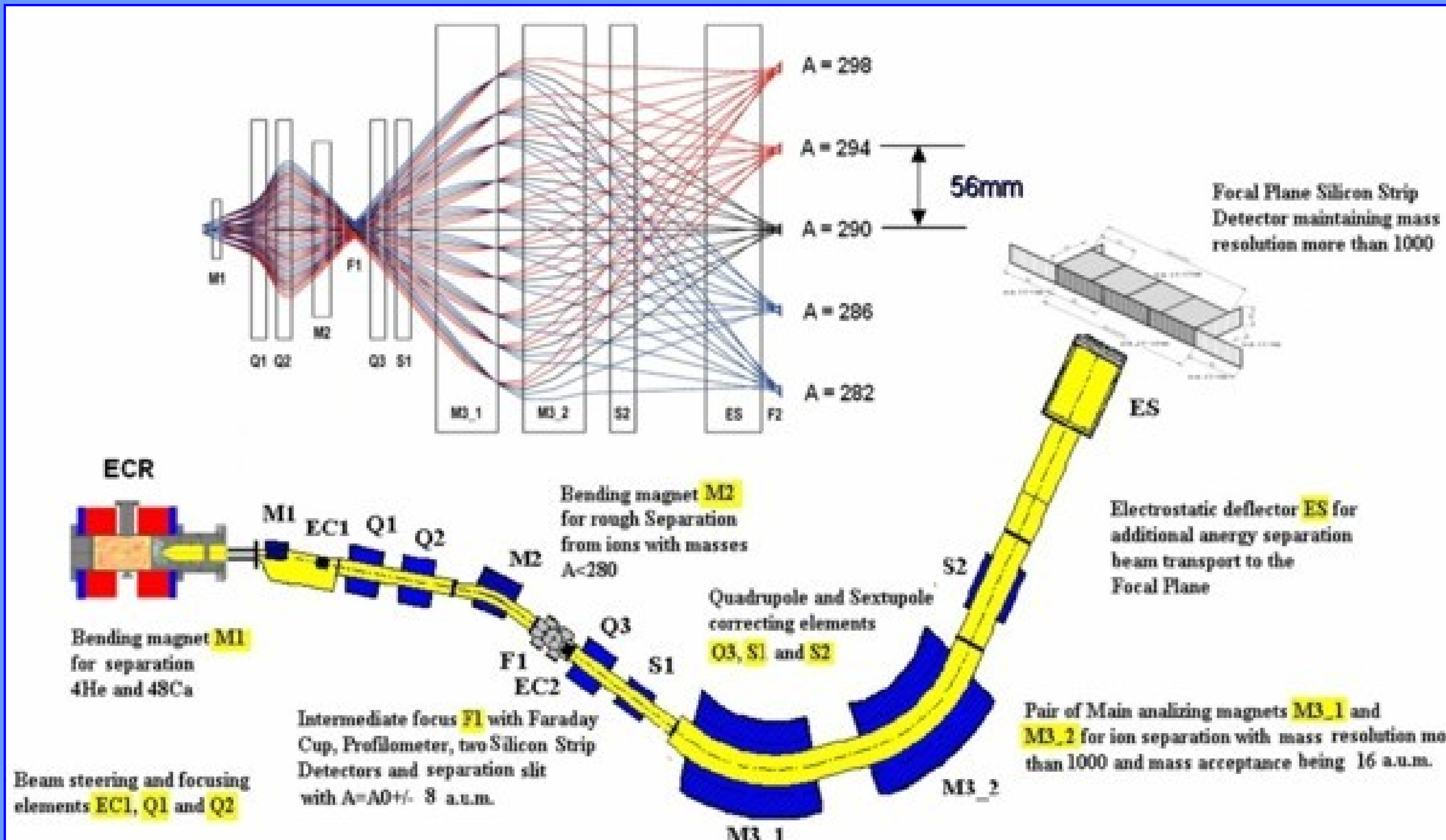
MASHA (Mass Analyzer of Super Heavy Atoms)



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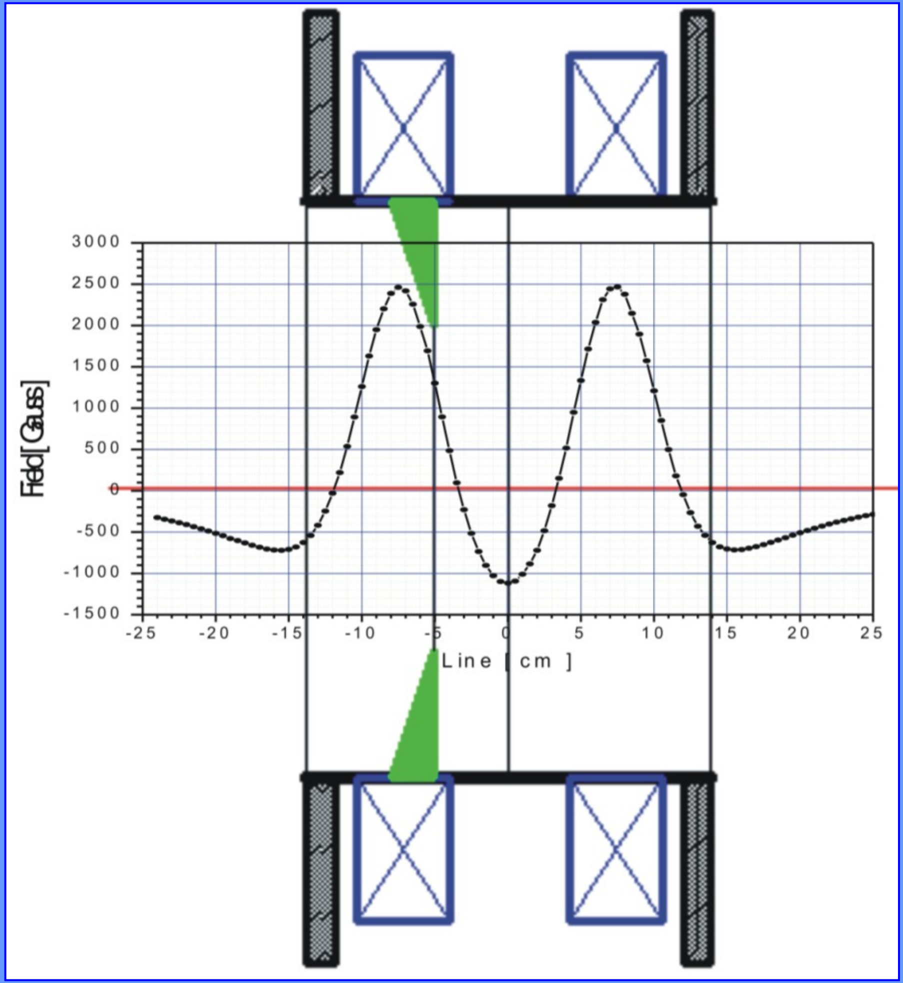
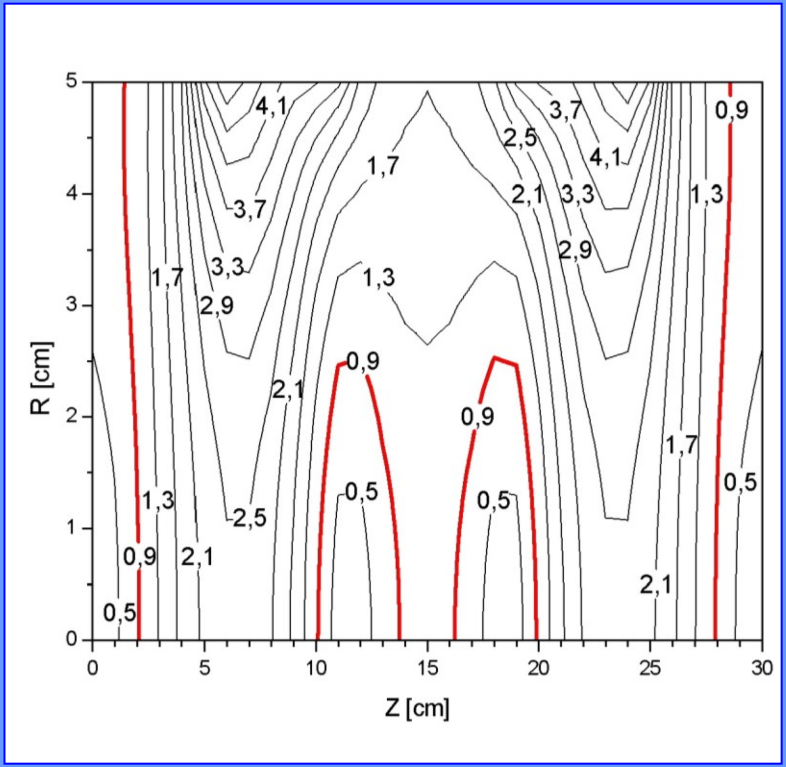
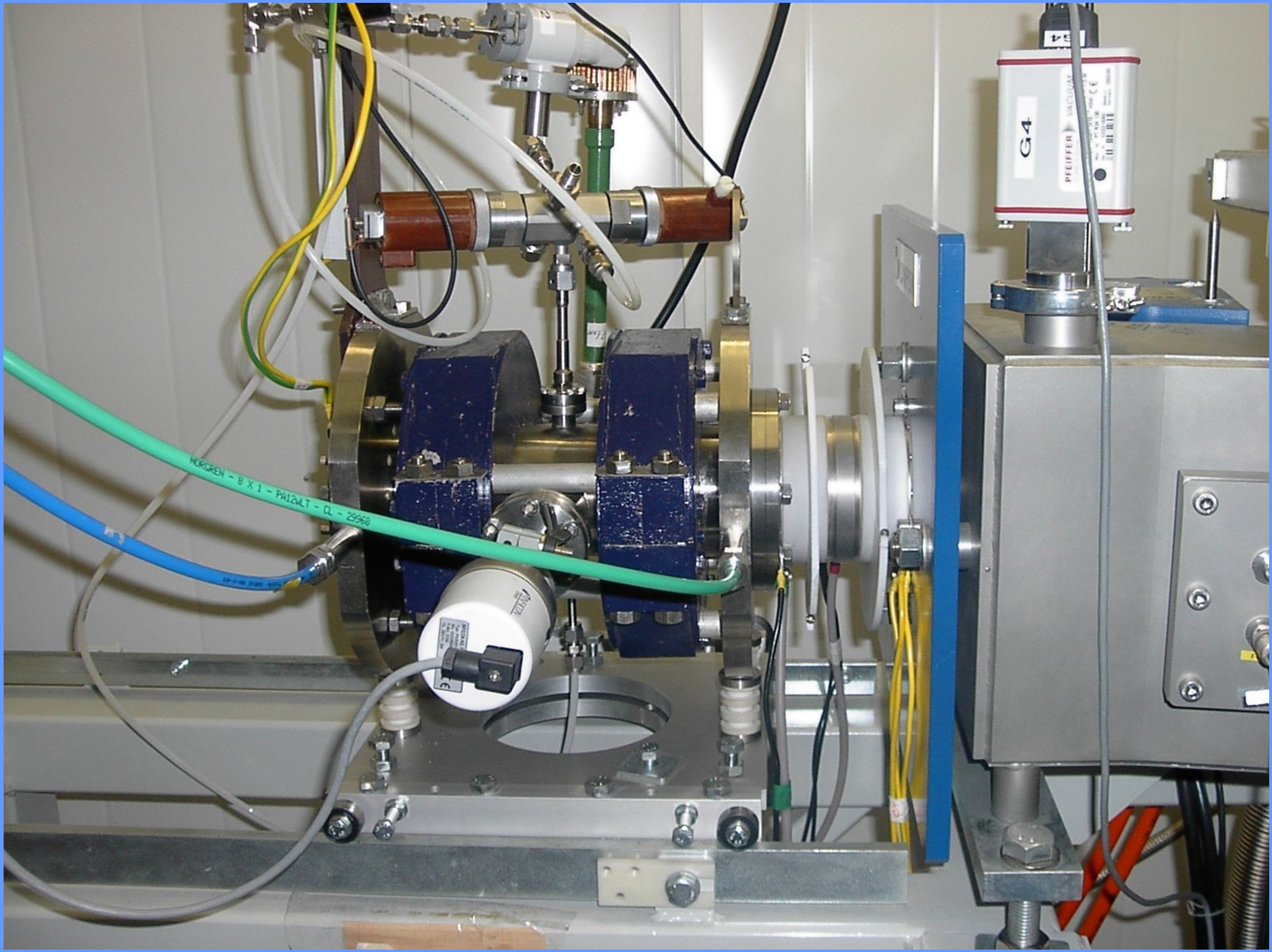
Magnetic structure of ECR ion source for MASHA (operating frequency 2.45 GHz)





ECR ion source for MASHA



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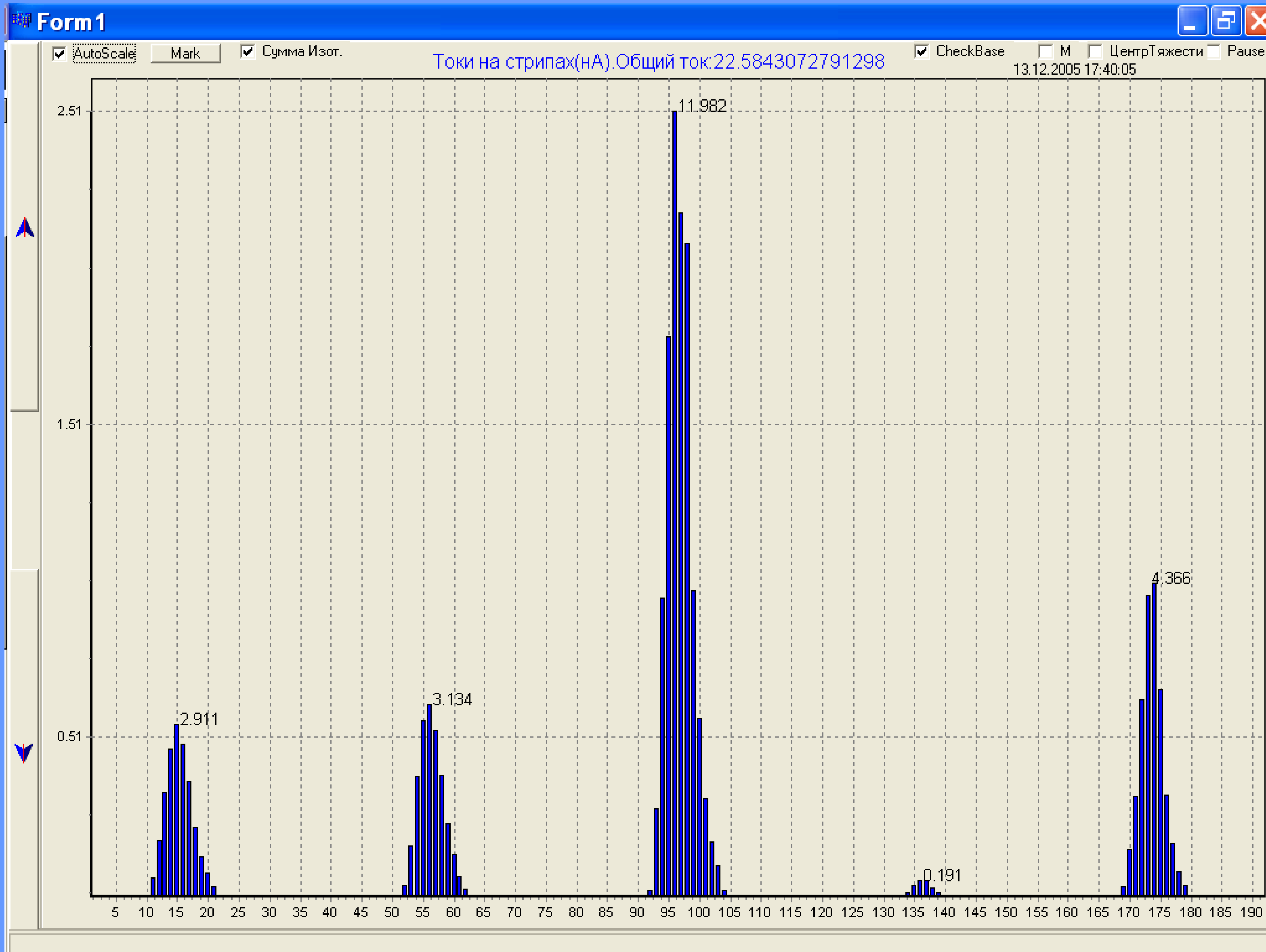
Kr spectrum

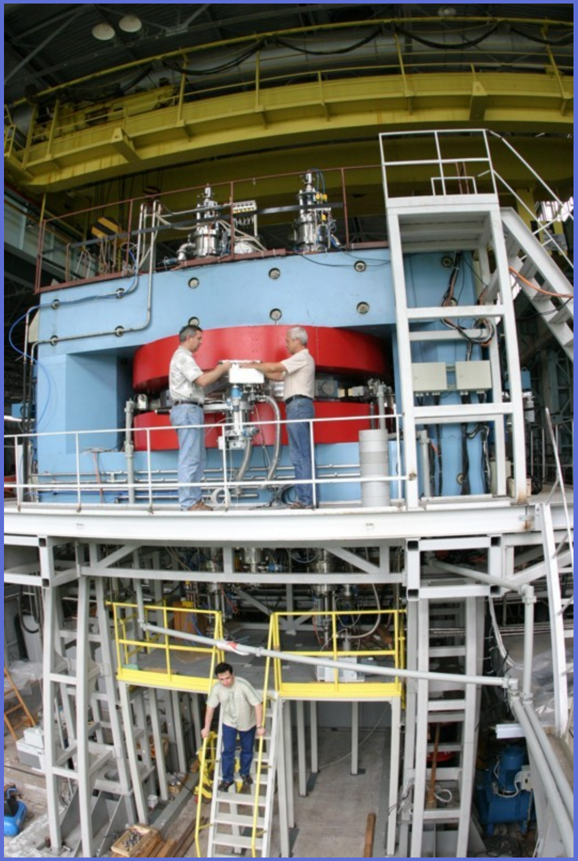


Total efficiency – 47%

Development and creation of ECR sources for other scientific centers

DC-72 + DECRIS-2m

At present, the cyclotron equipment has been produced in full, has passed full testing at the FLNR and is ready for shipment to Slovakia.



DC-60 + DECRIS-3

The cyclotron center creation started in the beginning of 2004, and at the end of 2006 the accelerator complex was put into operation, the first accelerated beams were obtained and the first experiments performed.

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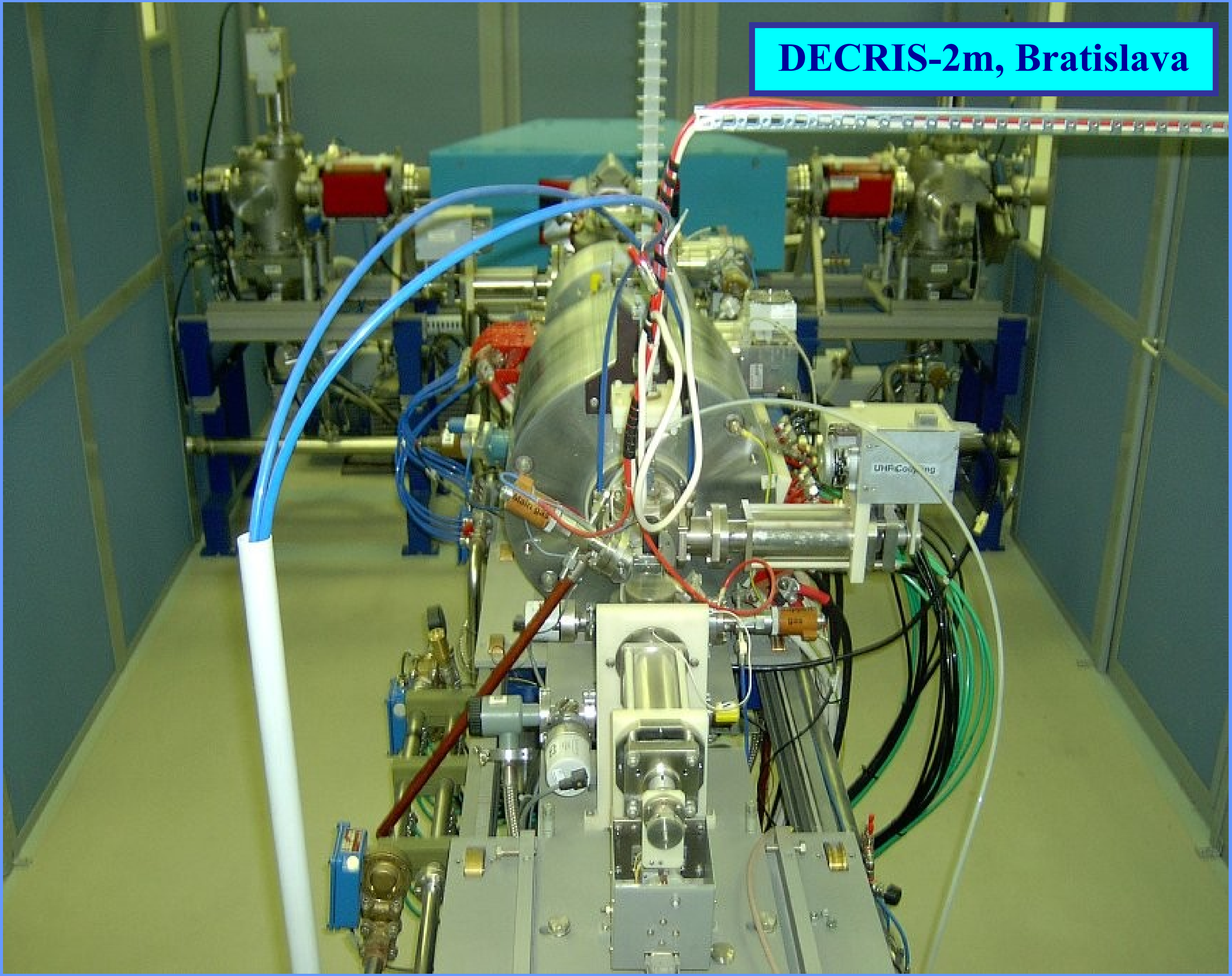
DECRIS-3, Belgrade

JINR

Dubna



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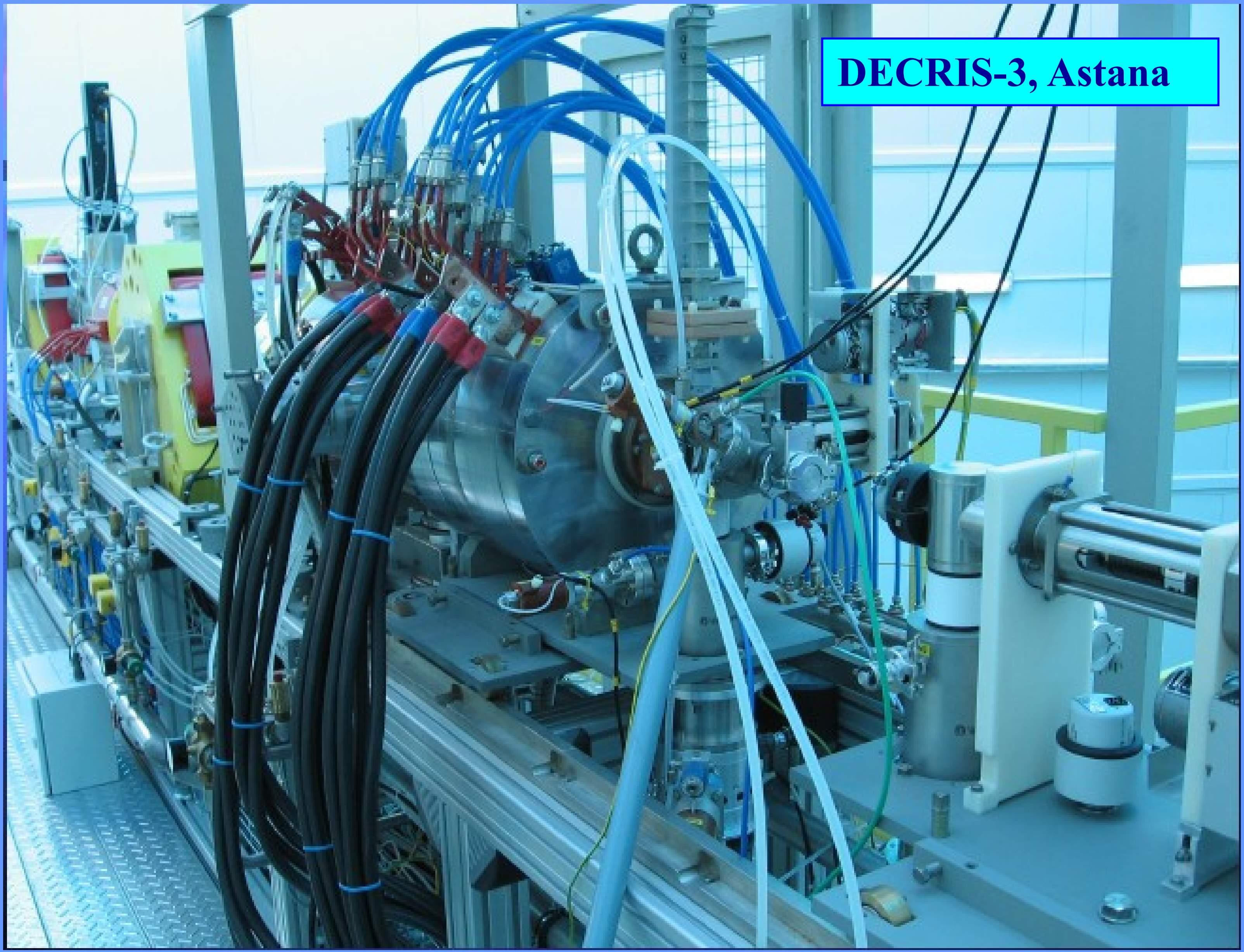

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THANK YOU!!